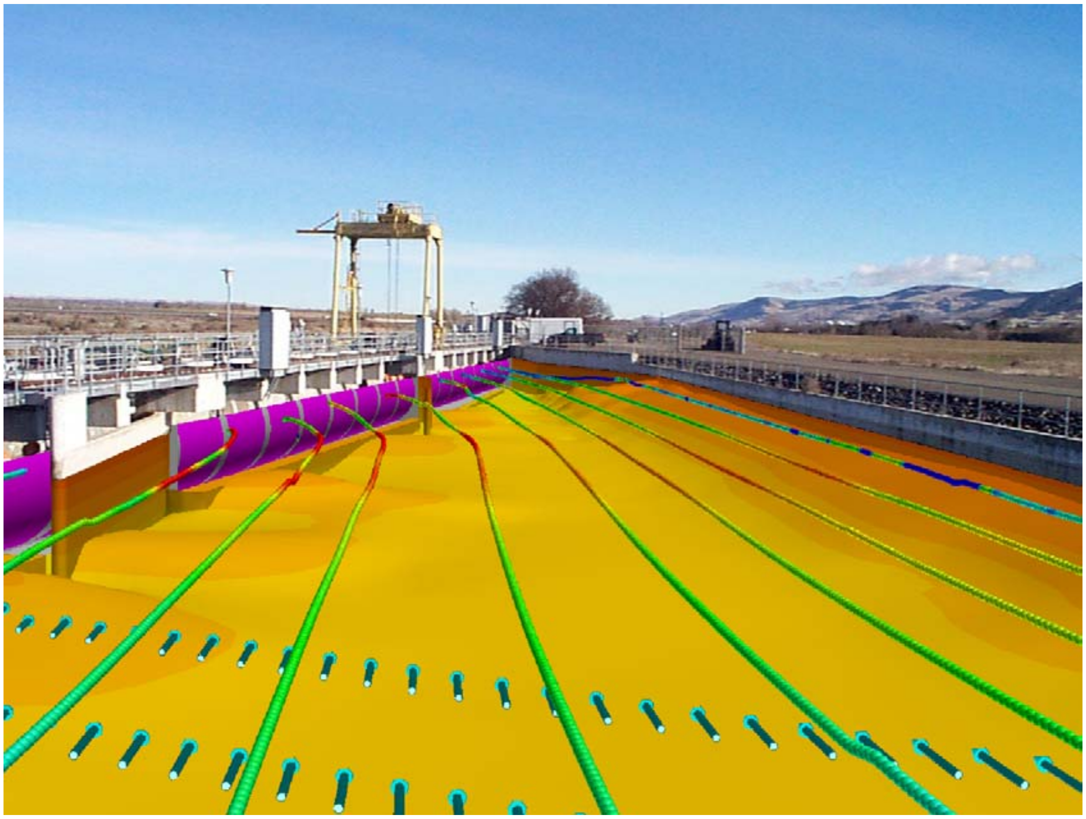
PNWD-3144

Chandler Canal Fish Screen Low Water Evaluations 2001



Final Report to

The U.S. Bureau of Reclamation
Yakima Project Office
Yakima, Washington

by

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Executive Summary

The drought of 2001 presented difficult challenges to water users throughout the western United States. The effects of this drought in Washington's Yakima Basin forced the U.S. Bureau of Reclamation to operate the Chandler Canal at flows well below those for which the canal and fish protection facilities were designed. The Chandler Canal Fish Screen Facility was designed to operate at maximum canal flows of 1500 cubic feet per second (cfs), while canal flows during the late spring and summer of 2001 were often below 700 to 800 cfs. This study was initiated to address concerns that the operation of this facility at these reduced flows might impact salmon survival. In this study, we determined whether the water velocities in front of the fish screens were within fish protection criteria set by the National Marine Fisheries Service (NMFS). We also used an electronic sensor fish device to determine whether conditions existed within the facility that might be expected to injure or kill passing fish. We reviewed the 2001 canal survival data and plotted the relationships between canal survival (for all salmonids combined in 2001) and canal flow, date, and water temperature. In addition, we constructed a computational fluid dynamics model of the facility and made model runs with the facility as is and with modifications intended to increase fish survival at a range of canal flows. Finally, we provided recommendations on how the facility might be modified or operated to increase salmonid survival should low canal flow operations be considered at the Chandler Canal in the future.

In general, water velocities in front of the screens met NMFS criteria. There were a few isolated "hot-spots" of approach velocities that were typically associated with either the areas downstream of the intermediate bypass training walls and/or the lower portions of the screens where the porosity boards were set to allow more water to pass along the forebay floor (screens 17 to 24 had gaps of 22 inches along the bottom, while screens 2 to 16 had gaps of 11 inches along the bottom).

The results from the sensor fish device deployments showed that passage through most areas within the facility would not be expected to result in fish injury or mortality. There were a few areas where the velocity vector magnitude change was slightly above the threshold that would be expected to cause some fish injury. These areas were in the terminal bypass pipe, the bypass from the separation camber to the Juvenile Evaluation Facility (JEF), and in the pipe from the JEF to the bypass outfall in the Yakima River.

The review of the fish entrainment data revealed that survival of salmonids through Chandler Canal was higher when canal flows were higher, date was earlier, and water temperature was lower. Because these variable interact, it is not possible to determine the relative effects of each of these variables, however, it is clear that passage through the canal at higher flows is more conducive to survival. Canal velocity may be a major factor in contributing to fish survival from the headworks of the canal to the JEF, but we did not have a full data set of canal velocities to compare to the canal survival data.

Computational fluid dynamics modeling provided a useful means of evaluating the relative effects of different canal flows and project modifications on water velocities and flow pathways

through the facility. Model results showed that the placement of holes in the training walls of the intermediate bypasses would be expected to reduce the hot-spot areas of high approach velocities observed downstream of these walls. Also, model results suggest that the placement of a temporary guide wall to block off the upper bay of eight screens would effectively increase forebay and sweep velocities, which should improve passage conditions for juvenile salmonids.

We also provided some ideas on ways to try to reduce the effects of predators within the facility. In our previous work at this site, we noted the presence of smallmouth bass in the entrances to all bypasses. The construction of engineered concrete fillets in the entrances to these bypasses would be expected to eliminate or greatly reduce the low velocity holding habitat for these predators. In addition, a more aggressive approach could be combined with this habitat modification, in which electrode arrays were placed in the bypass entrances. The periodic application of electric current to these arrays should provide a means of removing the predators—or deterring them from setting up territories in these passage constriction points.

We recommended that guide walls be considered within the fish screen facility and possibly through the canal to reduce cross-sectional area if low flows are expected to be run through the canal for long periods. The resulting increase in velocity through the canal would be expected to improve juvenile salmonid survival through the canal by reducing transit time and reducing the effectiveness of aquatic and avian predators. Further, we suggested that the placement of holes in the training walls might reduce or eliminate the hot-spot approach velocity problem areas downstream of intermediate bypass training walls. Also, placement of the porosity boards so that the gaps near the bottom were not as large should reduce the high approach velocities near the forebay floor.

Introduction

The meteorological conditions of the late winter, spring, and summer of 2001 produced severe drought effects throughout Washington State. The effects of the drought were especially pronounced in the Yakima River basin, one of Washington's most productive agricultural areas (Hart et al. 2001). By June 19, 2001, all of Washington was classified as being in moderate or severe drought (Figure 1).

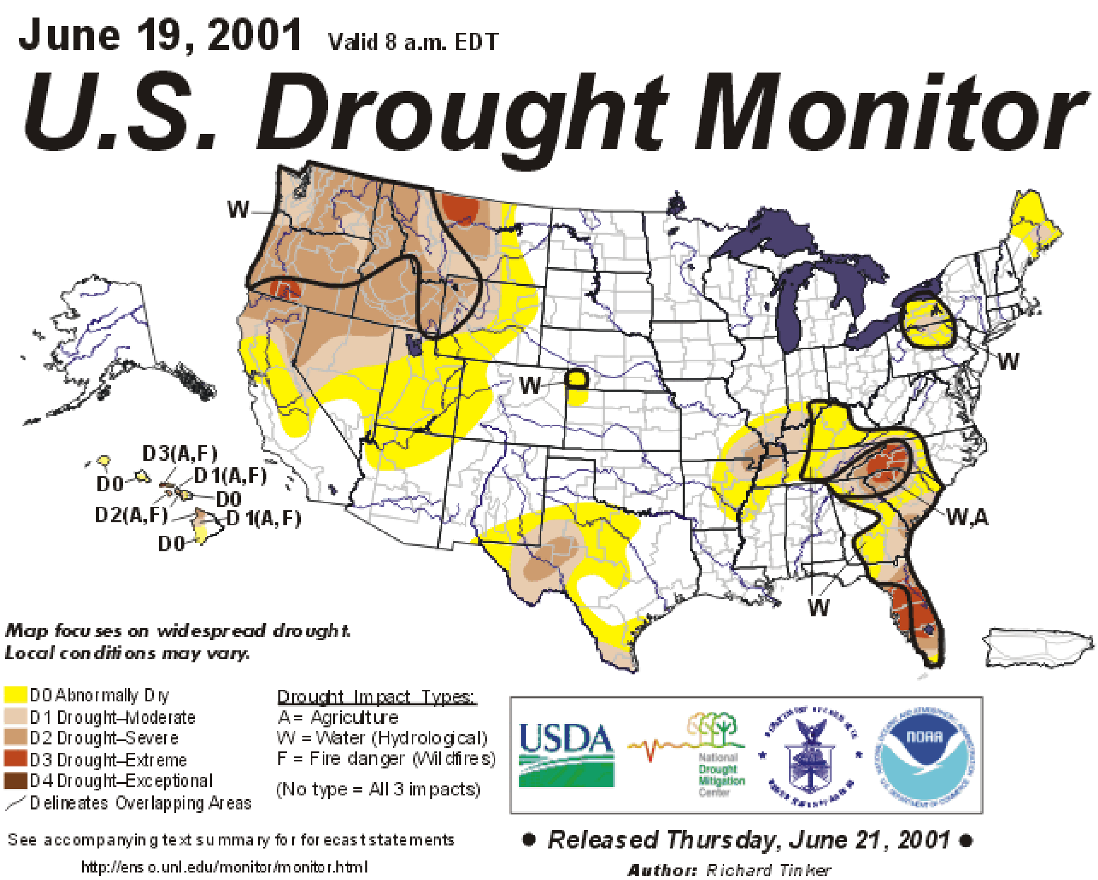

Figure 1. United States drought monitor for June 19, 2001.

These drought conditions affected passage conditions for juvenile anadromous salmonids attempting to emigrate from the Yakima Basin. Many fish screening facilities in the Yakima Basin were operated under flow conditions outside the design criteria for those facilities. Low river flow forced the U.S. Bureau of Reclamation (BoR) to operate the Chandler Canal Fish Screen Facility at canal flows that were well below the range of flows for which the facility was designed. In addition, the proposed Lower Yakima River Pump Exchange could reduce the canal flow to 700 cubic feet per second (cfs) if the exchange were implemented. The pump exchange would change the point of diversion for the Kennewick Irrigation District from the Prosser Dam/Chandler Canal to a pump station on the Columbia River. Therefore, due to the immediate drought concerns and the potential for longer-term low flows in the Chandler Canal, the BoR requested the evaluation of the fish screen facility on Chandler Canal to determine whether operating the facility at low flows would pose problems for migrating salmonids or violate National Marine Fisheries Service (NMFS) fish protection criteria for fish screens. Previous work by Battelle showed that the fish screens at the Chandler Canal facility generally met NMFS fish protection criteria at canal flows between 1200 and 1400 cfs (McMichael and Johnson 2001).

Battelle was contracted by the BoR to conduct a multifaceted evaluation of the Chandler Canal Fish Screen Facility under a range of flow conditions, with emphasis on canal flows that were below the design criteria of up to 1500 cfs. Specifically, the principal objectives of this study were to

- determine if low canal flows resulted in any conditions that would violate the NMFS fish protection criteria for juvenile fish screens
- evaluate the bypass down wells and bypass outfall to ensure that conditions do not exist there that would be expected to injure passing fish
- make recommendations that might lead to the reduction of habitat favorable to predator fish and expedite the safe passage of juvenile anadromous salmonids.

In addition, Battelle constructed a computational fluid dynamics (CFD) model to aid in determining the relative effects of canal discharge and certain project modifications on hydraulic characteristics that might affect fish passage through the facility.

Methods

Study Site

Chandler Canal is located on the left bank of the Yakima River near Prosser, Washington. The head gates of the Chandler Canal withdraw water from the Yakima River at the Prosser Diversion Dam at river mile 47.0 (Figure 2). The facility consists of 24 rotary drum screens (13.5 feet diameter, 12 feet long) and a fish bypass system composed of three fish bypasses (two intermediate and a terminal), a separation chamber with four bypass water recovery pumps located behind vertical traveling screens, and a fish return pipe. The water is removed from the bypass through the vertical traveling screens, passed over wooden weir structures and then into an underground pipe that returns to the bypass outfall in the Yakima River. The forebay elevation is about 631 feet (~75% submergence) at the maximum canal flow of 1500 cfs. The juvenile fish screen structure (Figure 3) is located on the canal approximately 1 mile downstream of Prosser Dam. The Chandler Canal conveys Yakima River water and all life stages of anadromous fish found in the Yakima (USDI 1986). The fish screen facility was designed to intercept the fish in the canal, concentrate them into a smaller volume of water, and then return the fish (and the smaller volume of water) back to the Yakima River. It should also be noted that the Chandler Canal Fish Screen Facility was originally designed for an approach velocity criteria (at that time) of 0.5 ft/sec. Current NMFS criteria call for approach velocities not to exceed 0.4 ft/sec.

Figure 2. Chandler Canal Fish Screen Facility (right center) near the Yakima River (left). The Juvenile Evaluation Facility (JEF) is the white building in the left center of the photograph. Photo courtesy of Dave Fast, Yakama Nation.

Water Velocities

Water velocities were measured using a Marsh-McBirney Model 511® electromagnetic water current meter. The meter uses a bi-directional probe that allows measurement of flows in two directions simultaneously. Output was read visually from a panel gauge and recorded on data forms. The probe was oriented such that the two measurement directions were normal (approach) and parallel (sweep) to the screens. Velocities were measured at four points on each drum screen at both 0.2 (high) and 0.8 (low) of depth (i.e., approach and sweep velocities were recorded at a total of 8 points on each drum screen). The 0.2 and 0.8 depths were in reference to the surface (with the surface being 0.0 and the forebay floor being 1.0), independent of what the sedimentation depth was at each point. In addition, bypass velocities were recorded within the bypass and outside the bypass entrance (equidistant between the screen and the training wall, about 8 to 10 feet from the terminus of the training wall). Water velocities were also recorded in

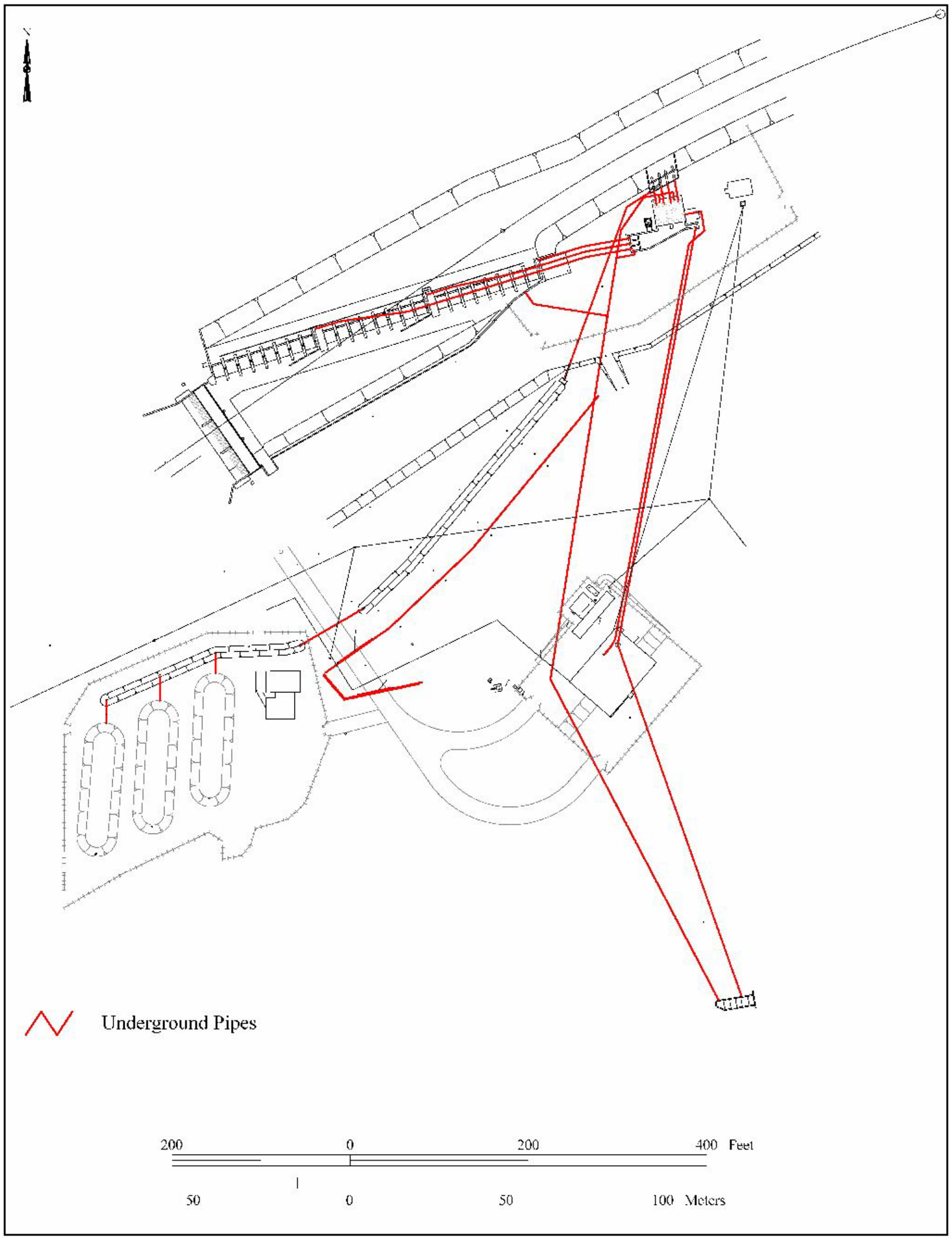

Figure 3. Plan view of the Chandler Canal juvenile fish screen facility. The structure in the lower right corner with two pipes leading into it is the fish bypass return box located in the Yakima River. Other pipes supply water to the Yakama Nation's hatchery facilities (modified from a graphic provided by Jim Faith, BOR).

the separation chamber near the vertical traveling screens, as well as in the terminal bypass. The operating conditions of each drum screen (e.g., on, off, new screen material, % screen submergence, etc.) were recorded on each survey. In addition, the relative position of the porosity boards was noted. Sediment depth was estimated at each measurement position by placing the steel rod that the velocity probe was attached to on the sediment surface and then pressing the rod through the sediment until it contacted the concrete forebay floor. Water velocities were measured at 9 different canal flows between 317 and 1214 cfs on 8 different dates between August 9 and December 21, 2001 (Table 1). Canal flows were measured by the BOR on August 9, September 28, and October 3. For all other dates, the canal flows we report were obtained from the BOR's Hydromet data. The Chandler Canal was dewatered for fall maintenance between the November 5 and December 17 sample dates. Therefore, all sampling on December 17, 20, and 21, was performed after the canal was returned to service.

Table 1. Sampling dates and flows (cfs) for water velocity and sensor fish device sampling at the Chandler Canal Fish Screen Facility during the low water period in 2001. Also reported is whether the dates sampled were before or after the annual canal maintenance and whether the water from the bypasses was passing under or over the weir structure adjacent to the separation chamber. The porosity boards were set the same for all evaluations (11 inches under boards at screens 2 to 16, 22 inches under boards at screens 17 to 24). Yakima River flow is from the Prosser Dam (YRPW) BOR Hydromet station.

Date	Canal Flow	Yakima River Flow	Water Velocities	Sensor Device	Before/After Maintenance	Under/ Over Weir
12/17/2001	317	2743	x		After	Under
12/17/2001	400	2806	x		After	Under
8/9/2001	503	285	x	x	Before	Under
8/27/2001	600	459	x		Before	Under
10/3/2001	692	409	x		Before	Under
9/28/2001	854	604	x		Before	Over
12/20/2001	1000	2343	x		After	Over
12/21/2001	1200	1998	x	x	After	Over
11/5/2001	1214	700	x		Before	Over

Approach velocities were regarded as "within criteria" if the mean velocity (at a given canal flow) was at or below 0.4 ft/sec. The NMFS has not made it clear whether one measurement in excess of 0.4 ft/sec is a violation of the criteria. Obviously, it would be best for the fish if no approach velocities exceeded 0.4 ft/sec. Even though fish screens are designed to spread the approach velocity evenly across the surface of the screens, it is rare that this is achieved in a constructed site.

Sensor Fish Device

Background

Laboratory studies have shown that fish can be injured when exposed to shear and turbulence. Injuries range from those that are acute and externally visible, such as bruises, scraping, tearing of tissues, and eye damage to chronic injuries observed by behavioral changes such as stunning, disorientation, and increased predation risk. Injury rate is correlated to the severity of the hydraulic environment, species and size of fish, and the orientation of the fish at the time of exposure. In general, injury rates are very low or zero until a threshold related to the severity of the exposure is exceeded. The LOEL (lowest observed effect level) is the point at which only minor injuries and no deaths are observed. After the threshold is exceeded, injury rates typically increase, often at high rates of change, until a high percentage, or all of the exposed fish are injured or killed (Neitzel et al. 2000).

Stunning, disorientation, and loss of equilibrium are commonly observed because of passage by fish through severe hydraulic environments and are believed to be a factor in increased susceptibility of fish to predation or other sources of indirect mortality. The biological factors resulting in these conditions are not known. Candidates for causal factors are temporary or permanent injury to the fish's vestibular system or brain. Injury mechanism candidates are impact and high rates of change of acceleration.

High rates of change of acceleration with respect to time are referred to as "jerk." Low jerk would indicate a less turbulent environment; high jerk a more highly turbulent environment. Jerk has been found to be important when evaluating the potential for damage to delicate instruments and is a factor in the comfort of passengers in conveyances such as trains, automobiles, elevators, etc. A typical design requirement for trains and similar conveyances is to keep jerk less than ~7 ft/sec^3. It is possible that jerk is a factor in the temporary disability of a fish's vestibular system, and this potential linkage is currently under investigation. Experiments conducted to evaluate the results of loss of vestibular function have been revealing. Dunn and Koester (1984) found that when the nerves to a fish's horizontal semicircular canal were cut, the fish could maintain equilibrium when at rest and appeared to swim normally. However, these fish were not able to complete avoidance maneuvers when startled. Since the semicircular canals provide information about angular acceleration (pitch, roll, yaw), fish with disrupted semicircular canals were observed to swim in a spiral when startled. Experiments conducted in microgravity, which disables elements of a fish's vestibular function, the function a fish uses to maintain equilibrium by sensing gravity and to detect linear accelerations (up-down, left-right, forward-back), have shown that fish resort to visual clues to establish and maintain equilibrium when their vestibular function is disrupted (Watanabe et al. 1991). Reliance on visual clues typically results in the fish orienting dorsally to light. This behavior might explain the tendency for many fish passed with spill and through turbines to move toward the surface following passage where they are more available to avian predators. Experiments such as these demonstrate that fish with disrupted vestibular function would likely be more vulnerable to predation even in those cases when equilibrium and swimming functions appeared normal. A jerk value of 2,000 ft/sec^3 corresponds to a change in acceleration of 10 g within a period of 0.005 seconds. This value of jerk is approximately twice that observed by Harper and Blake (1990) for rainbow trout (mean fork-length 1.24 feet) startle response fast-start. This value of jerk is assumed to be relatively safe for salmonids since their normal behavior could frequently result in changes in acceleration of this magnitude. No information is available to suggest the importance of the frequency of occurrence of jerk values >2,000 ft/sec^3; however, the increased susceptibility to predation of fish exposed to highly turbulent conditions (Neitzel et al. 2000) suggests that higher values of jerk might indicate increased risk of vestibular disruption. Cumulative frequency distributions for jerk were computed for all sensor fish releases.

Methods

The sensor fish devices used to characterize the physical environment encountered by fish during passage through the Chandler Canal bypass are cylindrical and are near neutrally buoyant. The casing is constructed of clear polycarbonate and is 7.5 inches long and 2 inches in diameter (Figure 4). The sensor fish device contains two types of transducers, a pressure transducer and three accelerometers in a tri-axial configuration. The remainder of the electronics consists of batteries, an analog to digital converter, memory, and communication components. Data are sampled at a rate of 200 Hertz, allowing 2 minutes of data recording at this sampling frequency, and are downloaded to a computer following recovery.

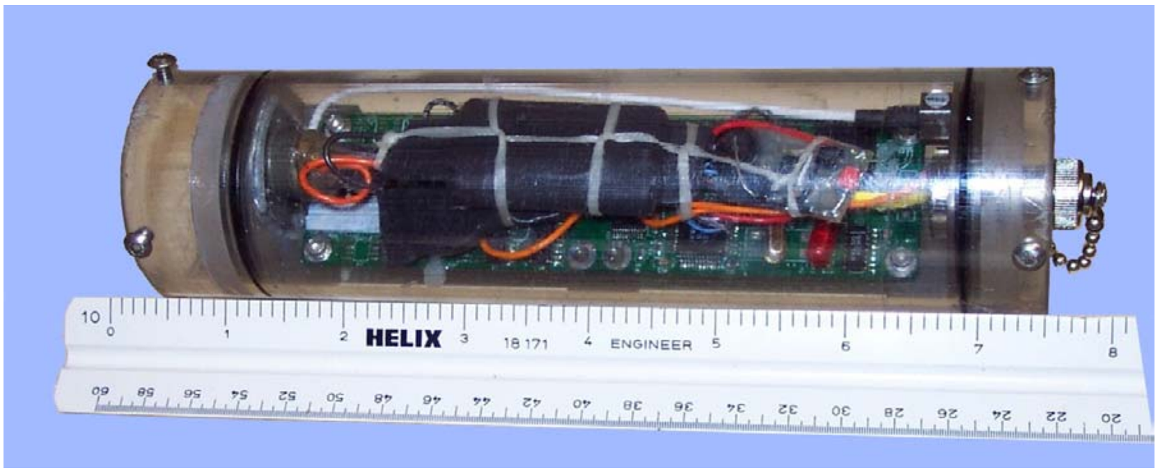

Figure 4. Sensor fish device.

The sensor fish device was designed to travel passively through hydraulic environments. It does not behave like a live fish, nor does it have structures that emulate the more sensitive features of live fish, such as eyes. Therefore, data obtained from the sensor fish device must be compared with injury to live test fish or some other means within the context of fish injury.

The sampled output from the accelerometers provides a detailed record of the response of the sensor fish device to hydraulic conditions during transit. Exposure to turbulence is evident in the accelerometer record by high magnitude, small duration changes in acceleration (higher jerk). The time history of pressure shows the depth of the sensor, as indicated by gauge pressure, as a function of time. The time histories of acceleration vector magnitude, jerk, and the magnitude of the velocity vector differential, indicate the amount of turbulence the sensor fish experienced and the impulse response of the sensor to impacts. The sensor fish output permits estimation of the retention time of the sensor in high energy dissipation environments, the duration and magnitude of turbulent cells, and features of the discharge jet trajectory.

The sensor fish pressure transducer measures total pressure, atmospheric plus static. During data processing, the total pressure measurements obtained from the sensor fish are adjusted for atmospheric pressure to obtain gauge pressure, i.e., hydrostatic pressure only. The adjustment factor for atmospheric pressure is obtained by computing the average pressure output from the pressure transducer during the time it is in air prior to placement into the fish injection system. This estimate of atmospheric pressure is subtracted from total pressure to provide estimates of gauge pressure. Water depth can be estimated from gauge pressure by dividing gauge pressure by 0.4335, which is the pressure in pounds per square inch (psi) of 12 inches of fresh water at a temperature of 39.2ºF.

During low flow conditions (503 cfs), the sensor fish devices were released into the second intermediate bypass, the terminal bypass, weir boxes (terminal, 1st intermediate, and 2nd intermediate), the separation chamber, and the bypass outfall at the Chandler Canal Fish Screen Facility.

During high flow conditions (1200 cfs), the sensor fish devices were released into the 1st intermediate bypass, the 2nd intermediate bypass, the terminal bypass, weir boxes, and the separation chamber. The bypass outfall was inaccessible for sensor fish device recovery. The sensor fish devices were recovered with the aid of a net, and data acquired in memory were downloaded to a computer. Following data recovery, the sensor fish device's memory was erased and the sensor was readied for its next deployment.

Fish Entrainment Data Review

Chandler Canal fish survival data from the Yakama Nation were reviewed for 2001 to examine relationships between canal survival, canal flow, date, and temperature. A correlation matrix was developed. Significant correlations were summarized to elucidate relationships between these variables. Lines were fitted to plots comparing canal survival with the other three variables. Lowess smoothing (robust locally weighted regression; [Cleveland 1979; 1984]) was used to fit the lines. In addition, we examined relationships between date, canal flow, and water temperature (recorded in the Juvenile Evaluation Facility). Forebay velocities were modeled with and without structural modifications using a computational fluid dynamics approach (see below). However, because not all flows (that existed during the survival releases) were modeled, we were not able to examine statistical relationships between the canal velocity and fish survival. We are assuming there is a relationship between canal flow and forebay/canal velocity but we did not collect data to develop an equation to describe this relationship.

Computational Fluid Dynamics Model

Objectives and Limitations

In this work, a computational fluid dynamics (CFD) model was developed for the Chandler Canal Fish Screen Facility forebay and drum screens for use in conjunction with velocity measurements made by Battelle. CFD models have been applied by Battelle in the forebay and tailrace of the Bonneville Project on the Columbia River (Rakowski et al. 2001). The STAR-CD CFD solver (Computational Dynamics 1999) was used for both the Bonneville and the Chandler simulations.

The numerical model of the Chandler Canal Fish Screen Facility forebay was used to simulate the overall velocity fields in the forebay for several discharges, and to simulate the effects of adding or removing structures. These simulation results were then used to compare the impact of the operational or structural changes.

There are inherent limitations in all numerical models. The numerical model is composed of the computational domain, which is based upon the system geometry. Boundary conditions, such as inflow or outflow specifications, are imposed on the model. Consequently, any numerical model will be limited by the definition of the geometry and boundary conditions. For the Chandler Canal Fish Screen Facility, the numerical model did not include features behind (downstream) the drum screens (e.g., the porosity boards), nor did the computational domain include the irrigation canal downstream of the drum screens. The flow split between the individual drum screens and the vertical flow distributions across individual drums were not well known. Typically, a numerical model for a location is developed, then the model validated with field-measured or reduced-scale physical model velocity data to ensure that the geometric data and boundary condition data represent the prototype. Validation data across the forebay was not available, although near-screen field measurements collected by Battelle were useful for validation purposes.

Methodology

Collection and Processing of Bathymetric Data

Some of the sediment in the Chandler Canal Fish Screen Facility forebay was moved and excavated by heavy equipment during a dewatered period in December 2001. A survey of the facility was conducted on December 13, 2001, during the dewatered period, so that the sediment in the forebay could be included in the numerical model. Although two benchmarks were located at the site, their geo-referenced coordinates were not available, although the elevations were known. The survey data were entered into a geographic information system (GIS), and data for the sediment at the bottom of the channel were used to develop an ARC/INFO GRID representing the bottom bathymetry.

Computational Mesh Development

A CFD model requires a computational mesh representing the system geometry. The schematic drawing from the 1:12 scale physical model was used as the basis for overall grid geometry. The lines were scaled from inches to feet in the GIS, and Battelle surveyed data were translated and rotated onto the same coordinate system. The lines of the schematic were exported into Gridgen (a commercial grid generation software [Chawner 2000]), and then combined with surveyed data to create a 3-dimensional unstructured mesh. The resultant mesh included existing features such as the drum screens, guide walls, ecology blocks, and surveyed sediment, as well as features being considered to improve flow conditions, such as the construction of a wall between the most upstream guide wall and the closest pier of the bridge, and holes cut into the intermediate bypass training wall in an effort to reduce or eliminate recirculation zones between the training wall and the first drum screen.

Validation

A complete validation data set including measurements throughout the forebay and through the drum screens for the existing conditions at multiple flows was not available. Consequently, recent near-screen velocity measurements by Battelle were used. These velocities were measured in four locations across each drum screen at 0.2 and 0.8 depths, in an effort to access compliance with NMFS mandated velocity criteria. Data collected on December 20, 2001, at a flow of 1000 cfs (Water Velocities section of this report) were used for comparison to the numerical model results.

Assumptions were made about the distribution of flow through the drum screens. The numerical model could be improved as more detailed field measurements become available. In the absence of better information, it was initially assumed that the total flow (minus fish bypass volumes) was distributed evenly across the drum screens and that 44 cfs passed through each fish bypass. The drum screens are represented as porous baffles passing fixed quantities of water. Initial assumptions suggested the total flow (minus fish bypass volumes) was distributed evenly across the drum screens and that 44 cfs (design flow) passed through each fish bypass. In an effort to validate this assumption, a single flow condition with a given forebay elevation was chosen. Field data indicate that higher flows passed through the most downstream bank, rather than being evenly distributed between the three screen banks. Consequently, distributions used in the model were 21%, 36%, and 43% from bank 1 to 3, respectively. Within the banks, flow was assumed to be distributed evenly between individual drums.

Simulations

Five flow scenarios were chosen to represent a broad range of flow conditions and structural scenarios. All simulations used the bed elevation surveyed on December 13, 2001. These scenarios are detailed in Table 2.

Table 2. Flow and physical configuration scenarios for conditions simulated with the computational fluid dynamic model of the Chandler Canal Fish Screen forebay.

Scenario	Total Discharge (cfs)	Bank 1	Bank 2	Bank 3	Guide Wall?	Training Wall Holes?
Case 1	1200	21%	36%	43%	No	
Case 2	1200	21%	36%	43%	No	Yes
Case 3	900	21%	36%	43%	No	
Case 4	700	21%	36%	43%	No	
Case 5	700	NA	46%	54%	Yes	
Case 6	500	NA	46%	54%	Yes	

The flow for each case was distributed between the drum screen banks as 21%, 36%, and 43% from upstream to downstream. For Case 5 and 6 (those with a guide wall), the proportional flow split between the second and third bank of drum screens was used. This split was 46% and 54%, from upstream to downstream, respectively.

Results

Water Velocities

Drum Screens

Water velocities at the Chandler Canal fish drum screens generally were within acceptable ranges relative to the NMFS criteria during all conditions that were sampled during the low canal flow periods in 2001. Approach and sweep velocities generally increased as canal flows increased. General flow measurement summaries will be presented first, followed by specific sections on each flow evaluated. Mean approach velocities were below the limit set by the NMFS under all conditions except at a canal flow of 1214 cfs on November 5, 2001 (Table 3 and Figure 5). On this date, the approach velocities were highest at the low (0.8 of depth) measurement point. This corresponds with the maximum gap in the porosity boards. With the larger gap under the porosity boards in the lower eight screens (22 inches versus an 11-inch gap under the boards behind the upper 16 screens), the approach velocities were generally higher at the lower (0.8 of depth) measurement position, while the inverse was true of the sweep velocities (Table 3). However, the porosity boards were set the same during all of our surveys (as described above). It is possible that the data collected on November 5 were somehow affected by electrical noise or interference, as the data are not consistent with those collected at similar flows on December 21, 2001. However, these velocities were very similar to those observed on June 15, 2000 (McMichael and Johnson 2001).

Sweep velocities also increased as canal flows increased (Figure 6). The ratio between sweep and approach velocity was acceptable (sweep velocity was greater than approach velocity), with respect to NMFS criteria, under all conditions evaluated (Figure 7).

317 cfs Canal Flow

On December 17, 2001, the Chandler Canal was held at 317 cfs while Battelle measured water velocities at the fish screens. Approach velocities were nearly all below the 0.4 ft/sec criteria (Figure 8). The only minor exception occurred at the low measurement on screen 17, which is immediately downstream of the second intermediate bypass training wall. This position was also the first screen of the lower bay of 8 screens where the porosity boards were 22 inches off the bottom. The sweep velocities were always higher than their corresponding approach velocities. With the exception of the first bay of eight screens, the sweep velocities did not tend to increase toward the bypasses. Sediment (silt and sand) depth was greatest in front of screens 5 to 7, 12 and 13, 17, and 20 and 21 (Figure 8).

Table 3. Summary water velocity data for the drum screens at the Chandler Canal Fish Screen Facility during evaluations conducted in 2001. High refers to 0.2 of depth; Low refers to 0.8 of depth.

Date	12/17/2001	12/17/2001	8/9/2001	8/27/2001	10/3/2001	9/28/2001	12/20/2001	12/21/2001	11/5/2001
Flow	317	400	503	600	692	854	1000	1200	1214
Drum Screens									
Average Sweep High	0.85	0.83	1.12	1.10	1.18	1.19	1.64	1.64	1.74
SD Sweep High	0.17	0.19	0.21	0.19	0.20	0.17	0.15	0.15	0.22
Average Sweep Low	0.65	0.59	0.88	0.90	0.89	0.86	1.09	1.12	1.21
SD Sweep Low	0.19	0.14	0.21	0.21	0.19	0.17	0.18	0.26	0.31
Average Combined Sweep	0.75	0.71	1.00	1.00	1.04	1.03	1.37	1.38	1.47
SD Combined Sweep	0.21	0.20	0.24	0.22	0.24	0.24	0.32	0.34	0.37
Average Approach High	0.16	0.12	0.16	0.03	0.16	0.23	0.16	0.19	0.31
SD Approach High	0.07	0.04	0.08	0.07	0.06	0.09	0.12	0.10	0.12
Average Approach Low	0.05	0.07	0.15	0.06	0.32	0.30	0.35	0.26	0.58
SD Approach Low	0.12	0.11	0.14	0.11	0.14	0.14	0.23	0.19	0.25
Average Combined Approach	0.10	0.09	0.15	0.04	0.24	0.27	0.25	0.23	0.44
SD Combined Approach	0.11	0.09	0.12	0.09	0.13	0.12	0.21	0.16	0.24
Percent Submergence	49.4	54.9	59.3	67.3	68.5	72.2	68.5	71.0	76.5

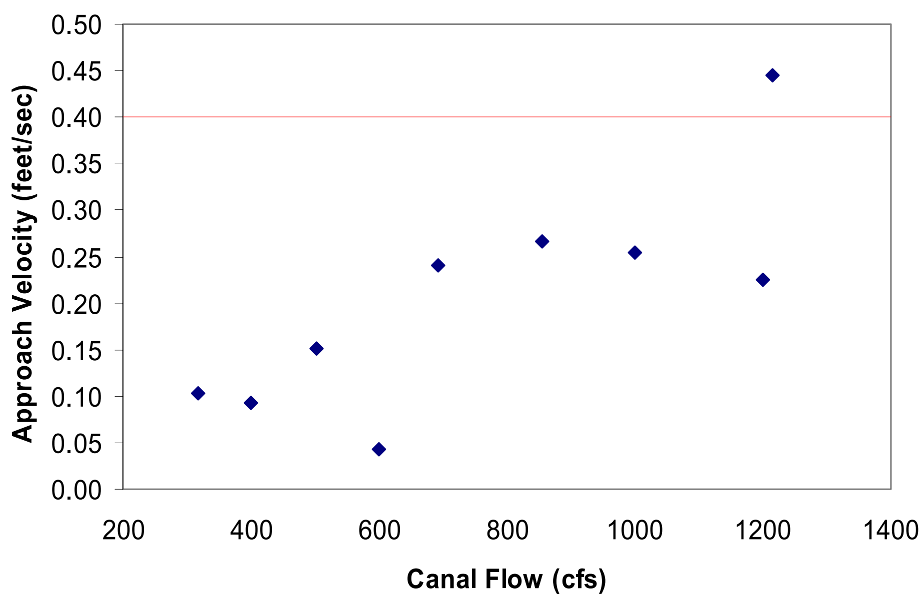

Figure 5. Mean approach velocity of all screens at the Chandler Canal Fish Screen Facility at various canal flows in 2001. The red line (at 0.40 ft/sec) represents the NMFS criteria for approach velocity. Values less than 0.4 ft/sec are within criteria.

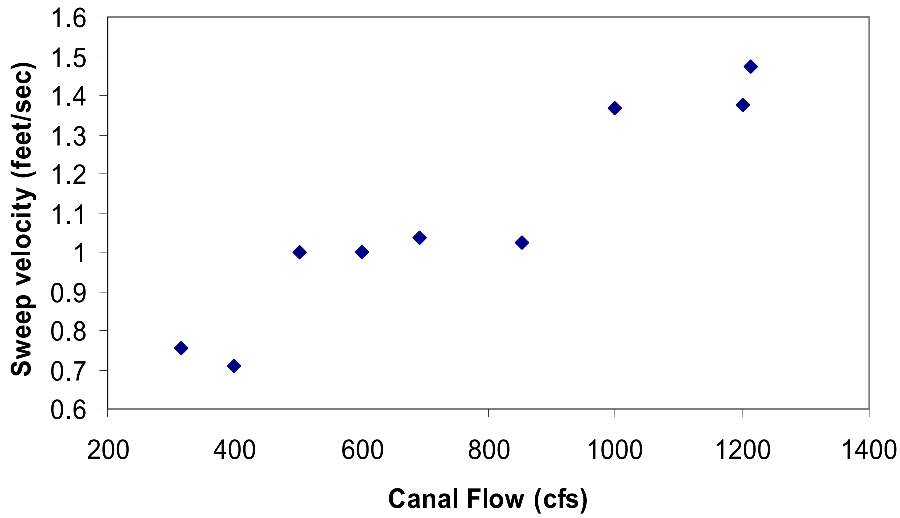

Figure 6. Mean sweep velocity of all screens at the Chandler Canal Fish Screen Facility at various canal flows in 2001.

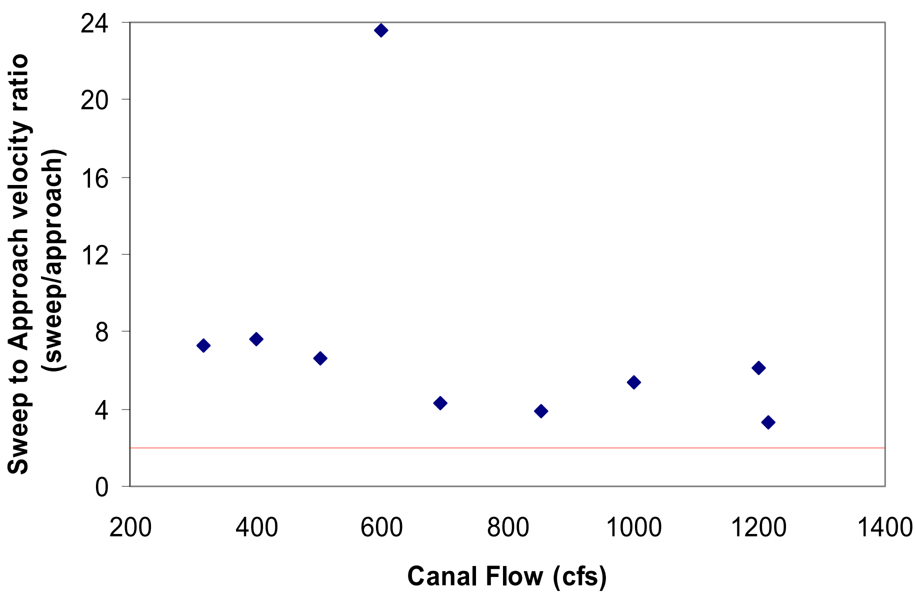

Figure 7. Sweep velocity to approach velocity ratio for the Chandler Canal Fish Screen Facility under various canal flows in 2001. The red line (at 2) represents a threshold of a mean sweep velocity that is twice as great as the mean approach velocity. NMFS criteria state that sweep velocity must be greater than approach velocity.

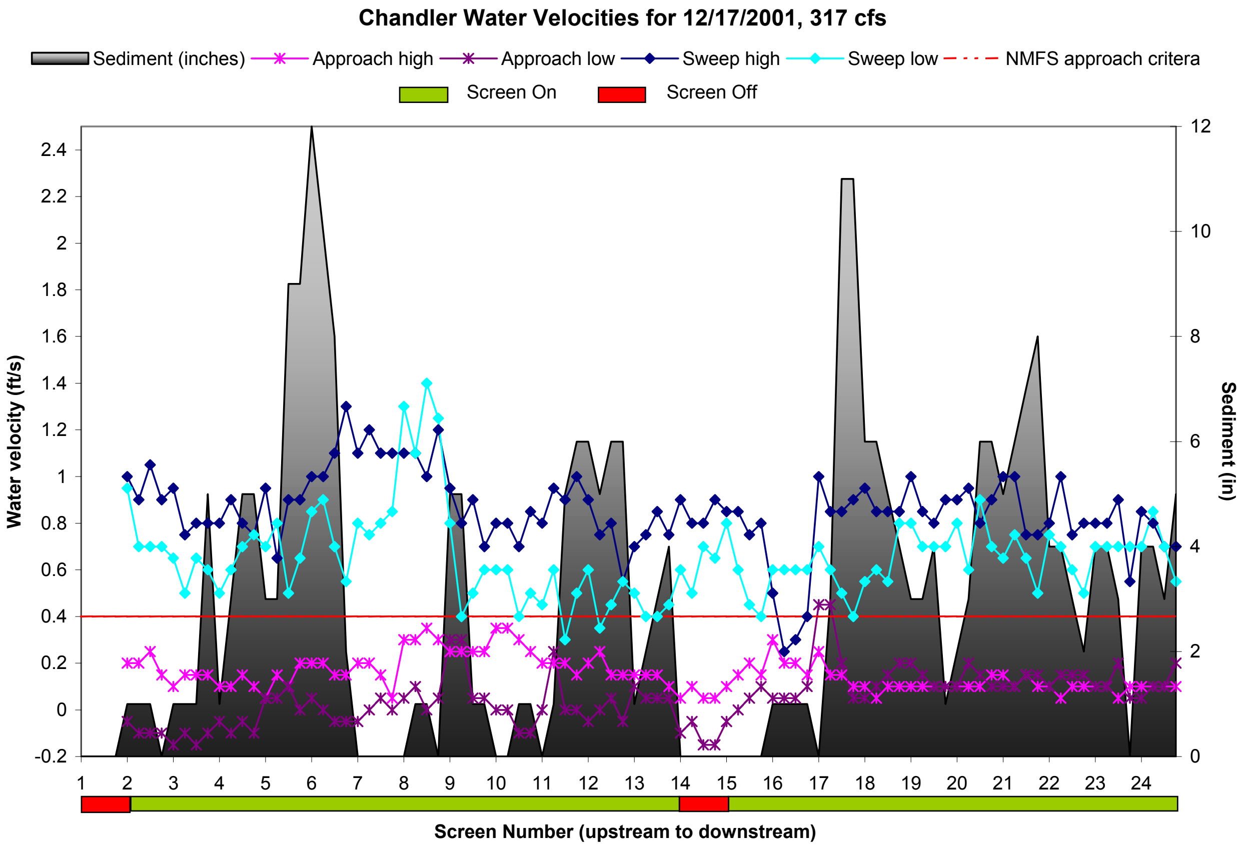

Figure 8. Approach and sweep velocity data at high (0.2 of depth) and low (0.8 of depth) positions for the Chandler Canal Fish Screen Facility at a canal flow of 317 cfs on December 17, 2001. The red line (at 0.40 ft/sec) represents the NMFS criteria for approach velocity. Values less than 0.4 ft/sec are within criteria. Sediment is displayed on the second Y-axis.

400 cfs Canal Flow

Measurements were repeated after canal flow was increased to approximately 400 cfs on the afternoon of December 17, 2001. Approach and sweep velocities at a canal flow of 400 cfs were very similar to those measured at 317 cfs (Table 3, Figure 8, and Figure 9). The mean low approach velocity was the only value that increased relative to the 317 cfs canal flow data, and this increase was very small (Table 3). As in the 317 cfs canal flow, the sweep and approach velocities followed very similar patterns, and the sediment data were the same on these two surveys.

503 cfs Canal Flow

On August 9, 2001, approach and sweep velocities were measured at the Chandler Canal Fish Screen Facility. Mean approach velocity was below the 0.4 ft/sec criteria limit when the canal was operated at 503 cfs (Table 3). Nearly all approach velocities recorded were below the 0.4 ft/sec limit, with the only exceptions occurring at the low sampling points on screens 17, 21,

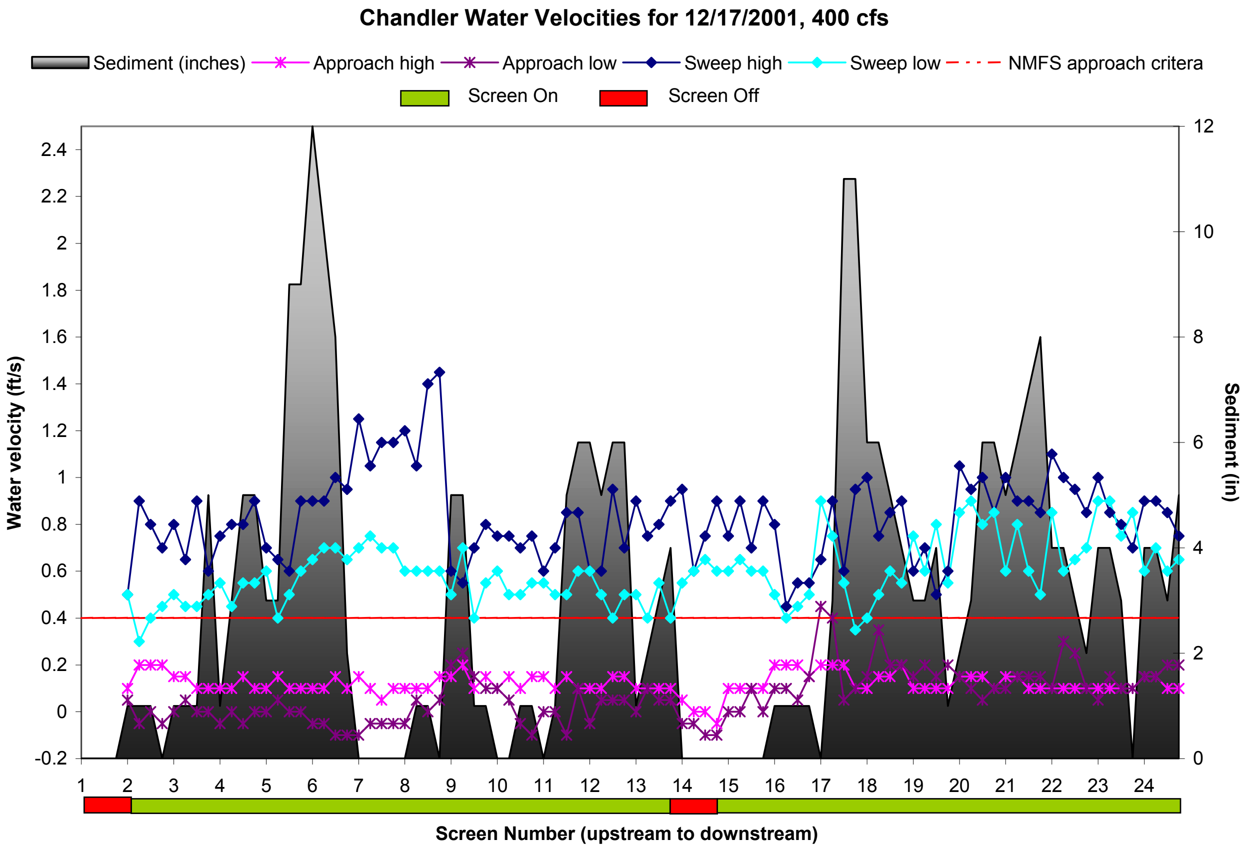

Figure 9. Approach and sweep velocity data at high (0.2 of depth) and low (0.8 of depth) positions for the Chandler Canal Fish Screen Facility at a canal flow of 400 cfs on December 17, 2001. The red line (at 0.40 ft/sec) represents the NMFS criteria for approach velocity. Values less than 0.4 ft/sec are within criteria. Sediment is displayed on the second Y-axis.

and 24 (Figure 10). Thirteen of the 23 operable screens were not rotating (off) at the time of this survey. These screens were typically covered in algae and diatoms and had reduced percent open area relative to the screens that were rotating. Sweep velocities showed good patterns of increase toward the downstream ends of the first two bays of screens (Figure 10). Sediment deposits were only observed in front of screens 5 and 18, which were not rotating and also were locations where Battelle measured very low approach velocities at the low (0.8 of depth) measurement position (Figure 10).

600 cfs Canal Flow

Chandler canal flow was at approximately 600 cfs on August 27, 2001, when Battelle measured water velocities at the Fish Screen Facility. Fourteen screens were not rotating during this survey, resulting in very low approach velocities and relatively high sweep velocities (Figure 11). All measured approach velocities were below the 0.4 ft/sec criteria limit. The sweep to approach velocity ratio for this survey was very high (Figure 7). These combinations of low approach and high sweep velocities would be expected to provide good fish passage

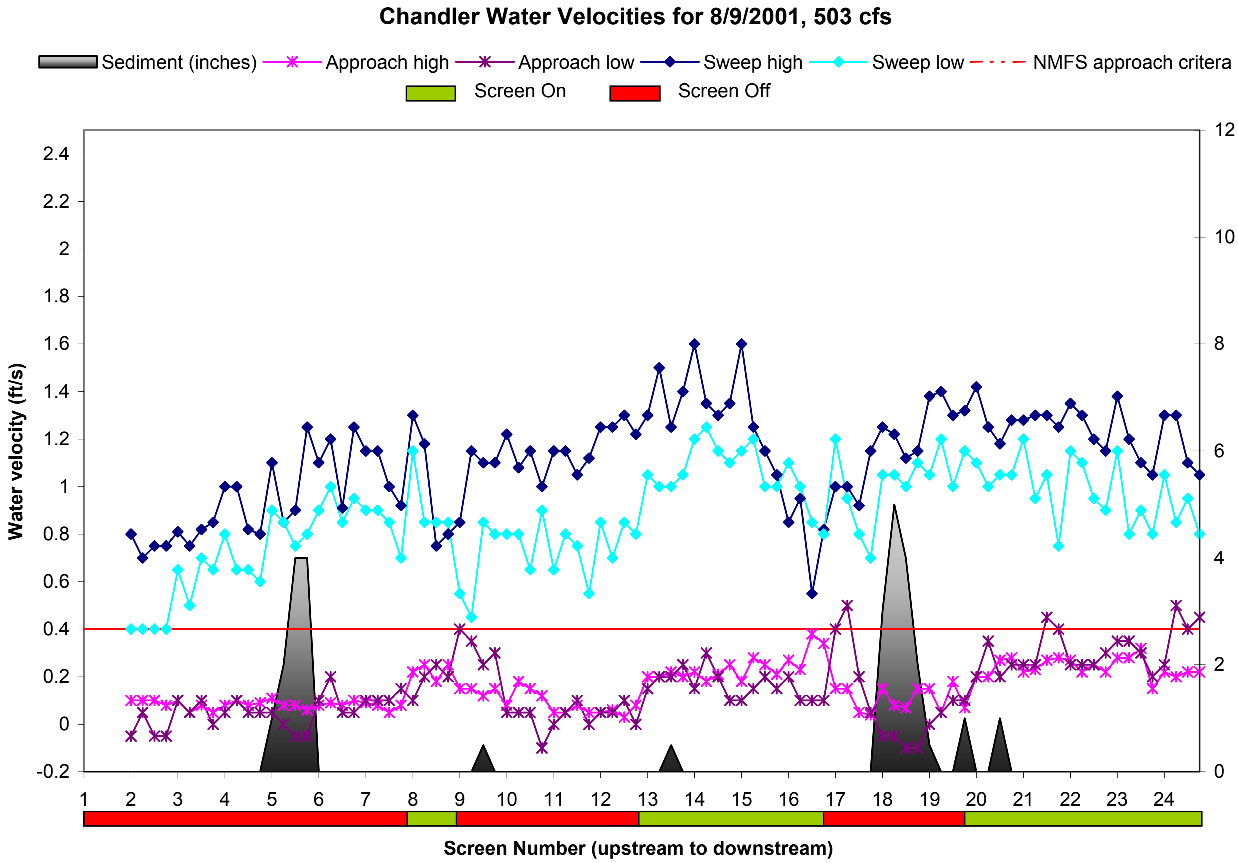

Figure 10. Approach and sweep velocity data at high (0.2 of depth) and low (0.8 of depth) positions for the Chandler Canal Fish Screen Facility at a canal flow of 503 cfs on August 9, 2001. The red line (at 0.40 ft/sec) represents the NMFS criteria for approach velocity. Values less than 0.4 ft/sec are within criteria. Sediment is displayed on the second Y-axis.

conditions. Sediment levels were minor and were reduced from the levels observed on August 9, 2001, possibly due to the increased sweep velocities resulting from turning 14 of the screens off for an extended period. This manner of operation (with over half of the screens turned off) appears to be a very good way to operate the facility at low flows. The effect of the algae and diatom growth on the screen material produced low approach velocities and relatively high sweep velocities that would be expected to pass fish effectively with minimal delay.

692 cfs Canal Flow

On October 3, 2001, we evaluated the Chandler Canal Fish Screen Facility when canal flow was at 692 cfs. All of the operable screens were turned on this survey date. The mean approach velocity was below the 0.4 ft/sec criteria (Table 3). However, approach velocities at the low measurement points (0.8 of depth) were in excess of the 0.4 ft/sec limit at the screens immediately downstream of the intermediate bypass training walls as well as at many points measured in front of the lower 8 screens (17 to 24) (Figure 12). Similar to the conditions

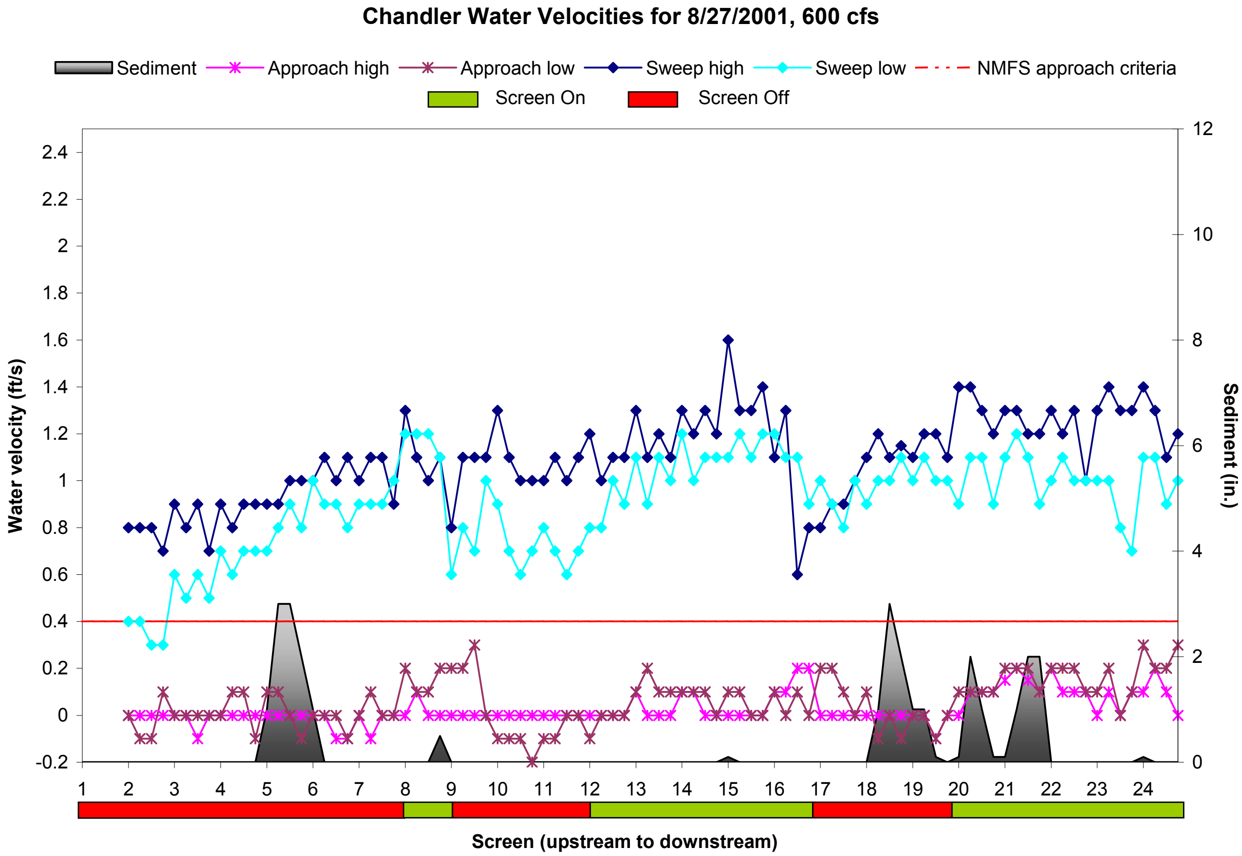

Figure 11. Approach and sweep velocity data at high (0.2 of depth) and low (0.8 of depth) positions for the Chandler Canal Fish Screen Facility at a canal flow of 600 cfs on August 27, 2001. The red line (at 0.40 ft/sec) represents the NMFS criteria for approach velocity. Values less than 0.4 ft/sec are within criteria. Sediment is displayed on the second Y-axis.

observed when canal flow was 300 cfs, the higher approach velocities near the bottom are likely due to the greater gap (22 inches) under the porosity boards behind the screens in this lower bay of 8 screens, relative to the screens upstream. Sweep velocities were generally very good and showed a slight increasing trend between screens 2 and 16 (Figure 12). The only appreciable amount of sediment observed was in front of screen 5. Compared to the approach velocities measured when the facility was operated at 600 cfs with 14 of the screens turned off, the approach velocities at 692 cfs were much higher, and in some locations exceeded the 0.4 ft/sec criteria. As previously stated, it appears that operating the facility with about half of the screens turned off when canal flows are low may be an effective way to aid fish passage.

854 cfs Canal Flow

Water velocities near the fish screens were again measured when Chandler Canal flow was at 854 cfs on September 28, 2001. Similar to the evaluations at lower canal flows, the mean approach velocity was below the 0.4 ft/sec criteria (Table 3). However, similar to the data observed at 692 cfs, there were some points where approach velocity exceeded the 0.4 ft/sec

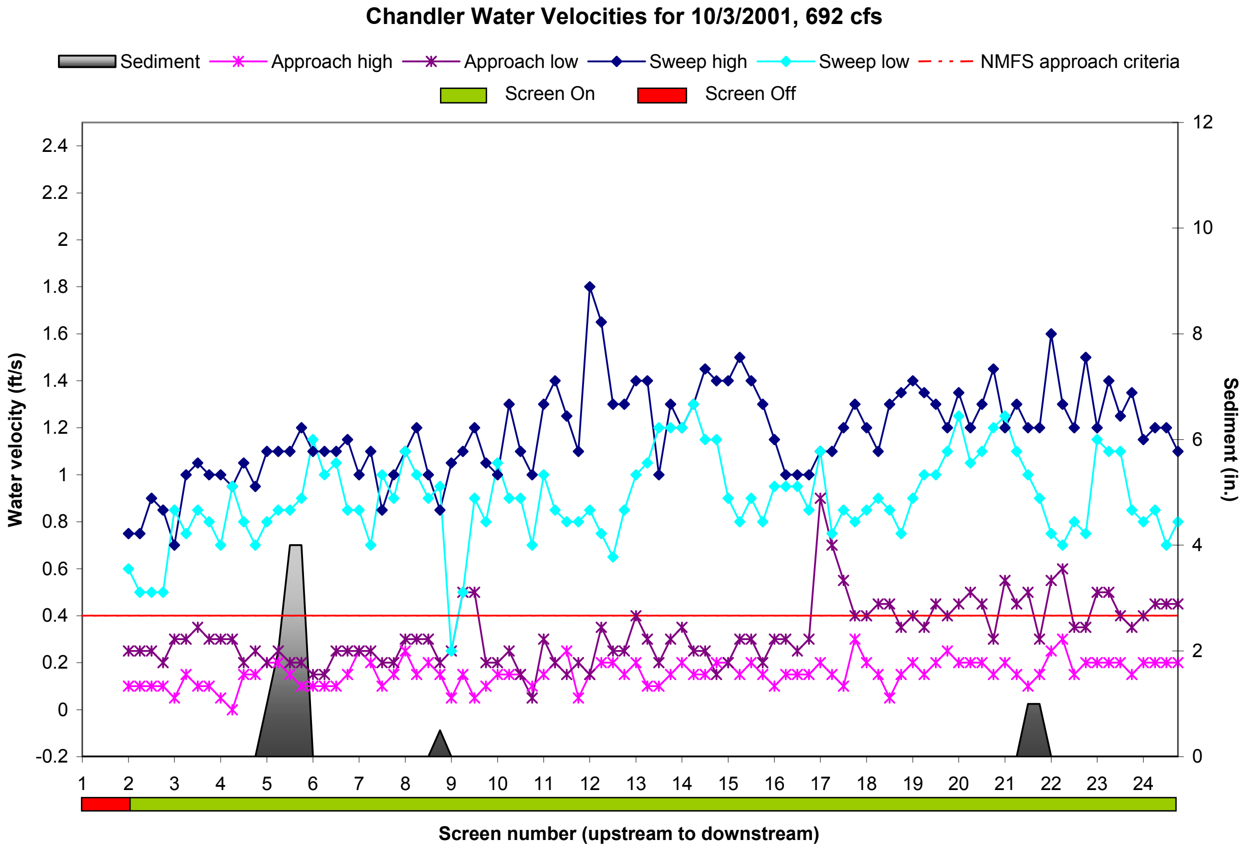

Figure 12. Approach and sweep velocity data at high (0.2 of depth) and low (0.8 of depth) positions for the Chandler Canal Fish Screen Facility at a canal flow of 692 cfs on October 3, 2001. The red line (at 0.40 ft/sec) represents the NMFS criteria for approach velocity. Values less than 0.4 ft/sec are within criteria. Sediment is displayed on the second Y-axis.

criteria. Again, these points were associated with the low measurements immediately downstream of the intermediate bypasses (screens 9 and 17) and along the lower portion of the last 8 screens (17 to 24) (Figure 13). Sweep velocities were well above approach velocities throughout most of the site, with the exception of those points associated with the downstream side of the intermediate bypass training walls (Figure 13). The only significant silt deposits were located in front of screens 5 and 21 concomitant with reduced approach velocities.

1000 cfs Canal Flow

Canal flow was approximately 1000 cfs when we surveyed the site on December 20, 2001. Mean approach velocities in front of the drum screens were less than the 0.4 ft/sec criteria at this canal flow of 1000 cfs (Table 3). Again, however, we observed approach velocities in excess of the criteria associated with the low measurements immediately downstream of the intermediate bypasses (screens 9 and 17) and along the lower portion of the last 8 screens (17 to 24) (Figure 14). Approach velocities were depressed in front of screen 14, which was not rotating. Sweep velocities were typically well in excess of the approach velocities, with the exception of

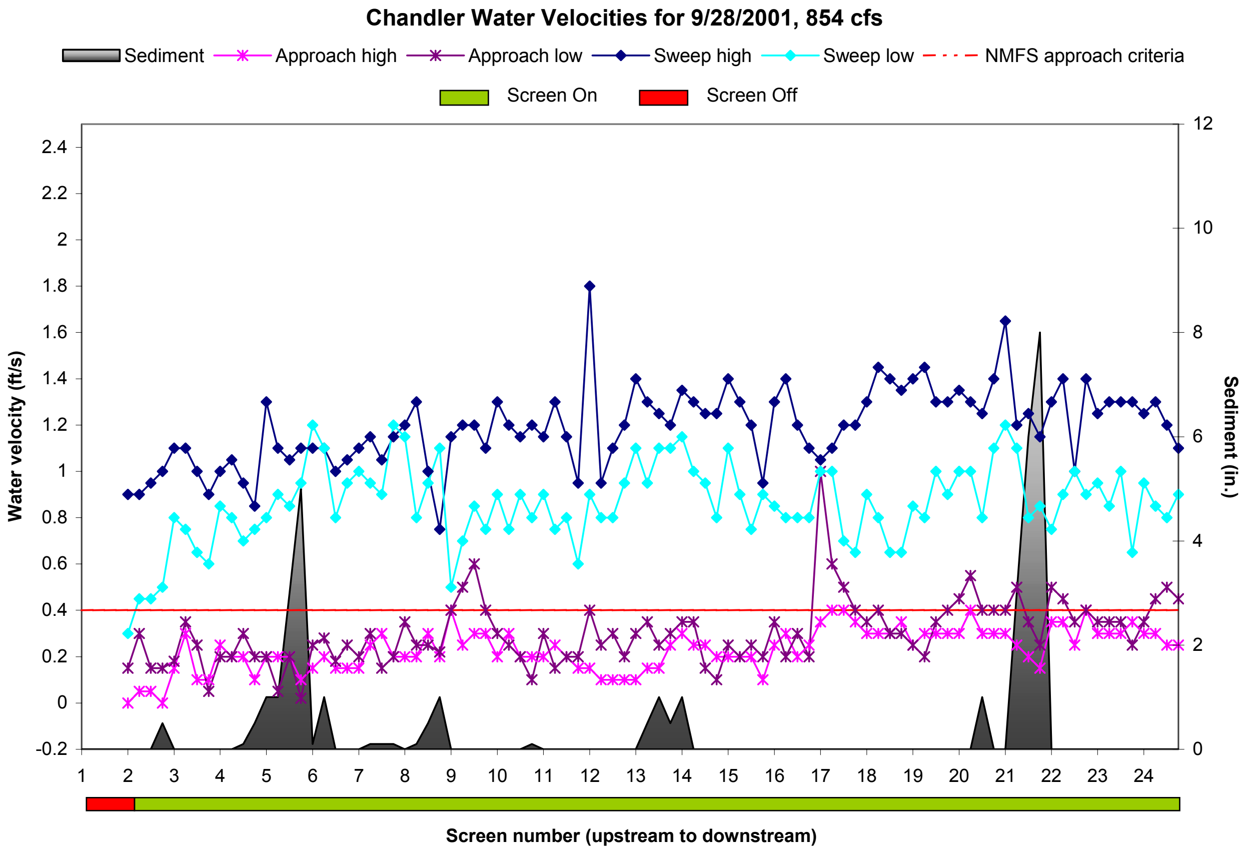

Figure 13. Approach and sweep velocity data at high (0.2 of depth) and low (0.8 of depth) positions for the Chandler Canal Fish Screen Facility at a canal flow of 854 cfs on September 28, 2001. The red line (at 0.40 ft/sec) represents the NMFS criteria for approach velocity. Values less than 0.4 ft/sec are within criteria. Sediment is displayed on the second Y-axis.

one point on the lower, upstream portion of screen 17 where the flow passing around the second intermediate bypass training wall creates a high approach velocity. Sediment deposits immediately in front of the screens were generally less than 3 to 4 inches deep.

1200 cfs Canal Flow

On December 21, 2001, velocity measurements were taken when the canal flow was at approximately 1200 cfs. The mean approach velocity in front of the drum screens when the canal flow was approximately 1200 cfs was again below the 0.4 ft/sec criteria (Table 3). However, we continued to observe a few points where the approach velocity exceeded the 0.4 ft/sec criteria, especially low (at 0.8 of depth) on the screens downstream of the intermediate bypass training walls (Figure 15). Again, approach velocities were low in front of screen 14, which was not rotating. Sweep velocities were again generally higher at 0.2 of depth, and lower at 0.8 of depth (Figure 15). Sweep velocities were again lower, especially at 0.8 of depth, in front of screens 9 and 17 (associated with the intermediate bypass training walls). It appears that

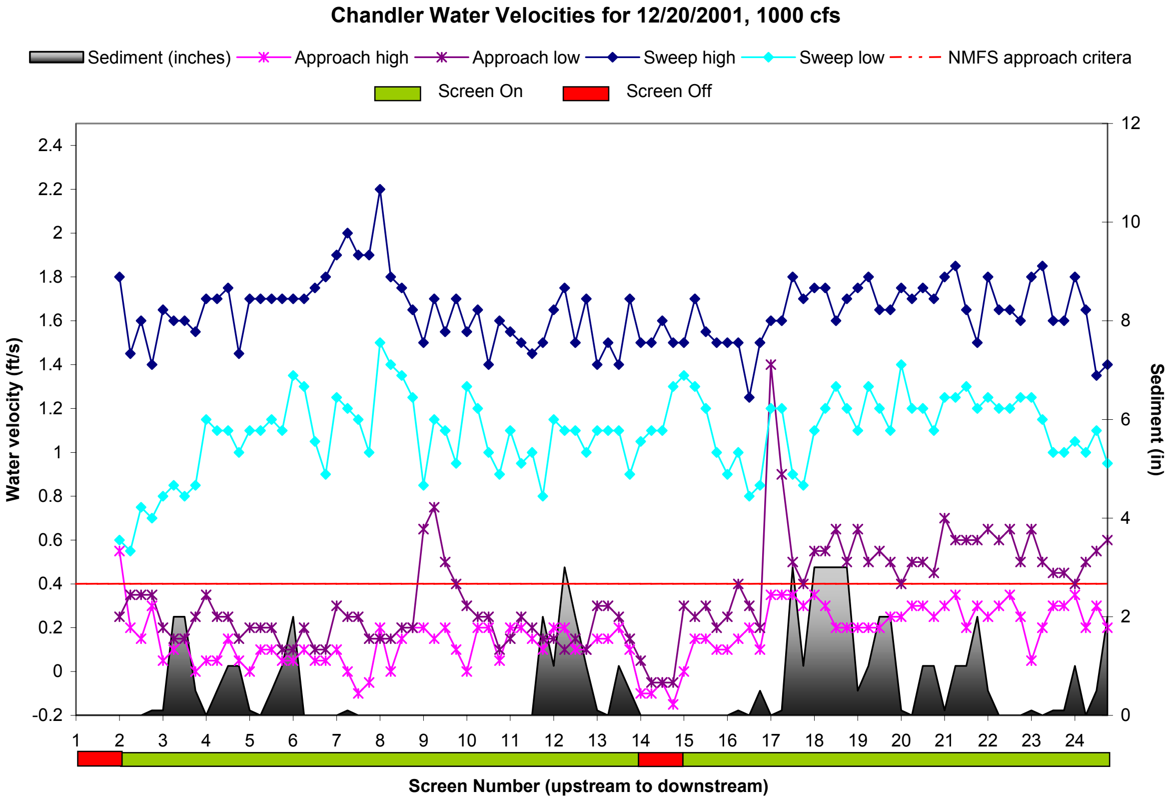

Figure 14. Approach and sweep velocity data at high (0.2 of depth) and low (0.8 of depth) positions for the Chandler Canal Fish Screen Facility at a canal flow of 1000 cfs on December 20, 2001. The red line (at 0.40 ft/sec) represents the NMFS criteria for approach velocity. Values less than 0.4 ft/sec are within criteria. Sediment is displayed on the second Y-axis.

some sediment moved into the area in front of the screens as the canal flow was increased from 1000 to 1200 cfs between December 20 and 21, 2001 (Figure 14 and Figure 15).

1214 cfs Canal Flow

The Chandler Canal flow was 1214 cfs during data collection efforts on November 5, 2001. Mean approach velocities in front of the drum screens were in excess of the 0.4 ft/sec criteria on this date (Table 3). However, there is a fairly large discrepancy between the approach velocity data collected on November 5 (1214 cfs) and December 21 (1200 cfs) (Figure 16 and Figure 15). This may have been due to the movement of sediments in the forebay or some other factor that changed because of the facility maintenance that occurred between the times these two evaluations were performed. These data (at 1214 cfs) were collected prior to the canal maintenance. Interestingly though, the data collected at a canal flow of 1214 cfs were very similar to data collected at this site on June 15, 2000, when canal flow was 1332 cfs (McMichael and Johnson 2001). The approach velocity patterns were also very similar between these two data sets, with the highest approach velocities occurring in front of screens 9 and 17. Mean approach flow was 0.43 ft/sec on June 15, 2000, and it was 0.44 ft/sec on November 5, 2001.

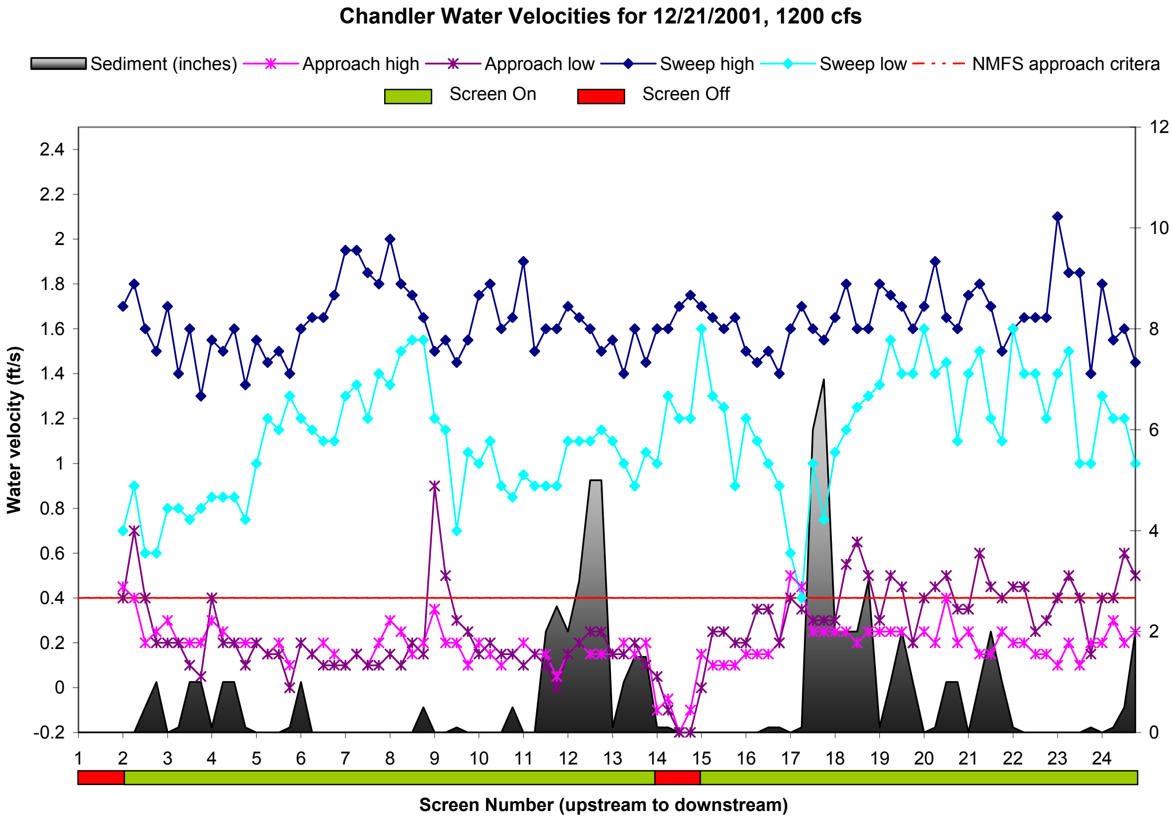

Figure 15. Approach and sweep velocity data at high (0.2 of depth) and low (0.8 of depth) positions for the Chandler Canal Fish Screen Facility at a canal flow of 1200 cfs on December 21, 2001. The red line (at 0.40 ft/sec) represents the NMFS criteria for approach velocity. Values less than 0.4 ft/sec are within criteria. Sediment is displayed on the second Y-axis.

Traveling Belt Screens

Approach and sweep velocities were measured in front of the traveling belt screens in the separation chamber on the same dates as those listed for drum screen measurements. The mean approach velocities in front of the traveling belt screens in the separation chamber exceeded the 0.4 ft/sec approach velocity criteria on 5 of the 9 dates sampled (Table 4). It is likely that the reduced area for water to pass through these screens is responsible for these high approach velocities. Plans are under way to replace the two existing traveling belt screens with four new stainless steel belt screens (J. Dyson, U.S. Bureau of Reclamation, personal communication). The doubling of the area of screen in the separation chamber should be an effective solution to the approach velocity problems there. A doubling of the screen area should reduce the mean approach velocities by roughly 50% (if the percent open area of the screen material and the total discharge (cfs) being removed from the chamber are unchanged). Sweep velocities in front of the traveling belt screens in the separation chamber were always greater than approach velocities and in all cases except one (692 cfs on October 3, 2001), were at least twice as high as approach velocities (Table 4).

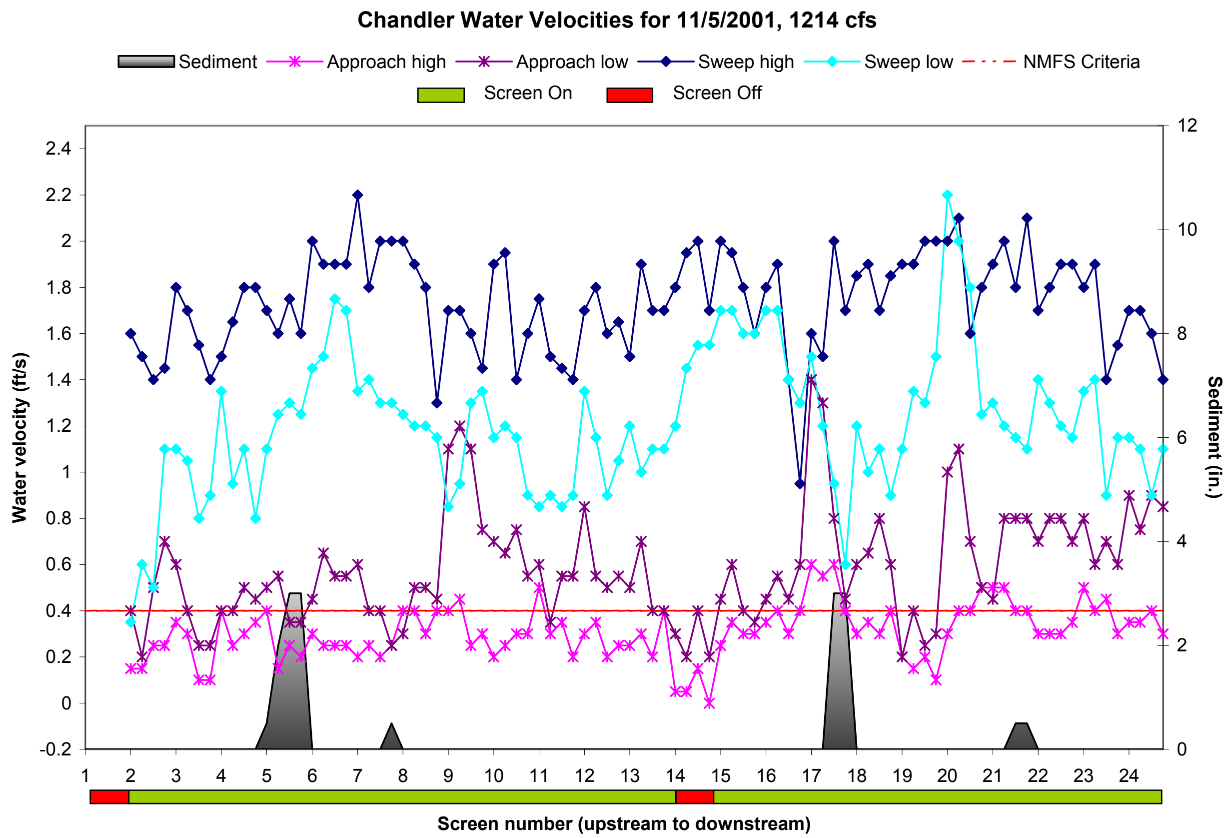

Figure 16. Approach and sweep velocity data at high (0.2 of depth) and low (0.8 of depth) positions for the Chandler Canal Fish Screen Facility at a canal flow of 1214 cfs on November 5, 2001. The red line (at 0.40 ft/sec) represents the NMFS criteria for approach velocity. Values less than 0.4 ft/sec are within criteria. Sediment is displayed on the second Y-axis.

Table 4. Summary water velocity data for the traveling belt screens in the separation chamber at the Chandler Canal Fish Screen Facility during evaluations conducted in 2001. High refers to 0.2 of depth; Low refers to 0.8 of depth.

Date	12/17/2001	12/17/2001	8/9/2001	8/27/2001	10/3/2001	9/28/2001	12/20/2001	12/21/2001	11/5/2001
Flow	317	400	503	600	692	854	1000	1200	1214
Belt Screens									
Average Sweep High	0.77	0.52	1.08	3.75	1.23	2.32	2.18	2.22	2.15
SD Sweep High	0.37	0.73	0.55	1.04	0.50	0.51	0.29	0.40	0.44
Average Sweep Low	0.77	1.02	1.45	3.00	0.70	0.93	0.83	1.82	2.07
SD Sweep Low	0.36	0.43	0.36	0.80	0.46	0.41	0.52	0.29	0.35
Average Combined Sweep	0.77	0.77	1.26	3.38	0.97	1.63	1.51	2.02	2.11
SD Combined Sweep	0.35	0.63	0.48	0.97	0.54	0.85	0.81	0.39	0.38
Average Approach High	0.18	0.10	0.46	0.19	0.50	0.43	0.18	0.41	0.52
SD Approach High	0.14	0.27	0.23	0.53	0.17	0.14	0.10	0.05	0.27
Average Approach Low	0.06	0.33	-0.31	1.38	0.58	0.68	0.48	0.73	0.65
SD Approach Low	0.16	0.20	0.31	0.52	0.32	0.28	0.36	0.12	0.21
Average Combined Approach	0.12	0.22	0.08	0.78	0.54	0.56	0.33	0.57	0.58
SD Combined Approach	0.16	0.26	0.48	0.80	0.25	0.25	0.30	0.19	0.24

Bypass Velocities

Water velocities within the bypasses (near the ramp) and about 8 to 10 feet outside the bypass entrances were generally between 1.2 and 2.4 ft/sec (Table 5). However, the velocities inside the separation chamber bypass were generally higher than those in the screen forebay. Velocities outside bypass entrances were typically about half the velocities within the bypasses. NMFS criteria call for bypass velocities within the pipe to be 2.0 ft/sec or greater. Our measurements indicated that the bypass velocities in the concrete channel outside the pipe were within criteria in a little over half of the measurements (not including the bypass from the separation chamber to the JEF – which always exceeded 2.0 ft/sec). Typically, the bypass velocities were within criteria more when canal flows were higher, although all bypass velocities were within criteria when the canal flow was at 600 cfs and 14 of the screens were not rotating. Our bypass velocity measurements were made outside of the entrance to the pipes and we expect the velocity within the pipes to exceed those in the concrete channel where our measurements were made. NMFS criteria also state that the velocities within the bypasses must be greater than velocities upstream (outside) of the bypasses. This condition was met in all cases (Table 5).

Table 5. Water velocities 8 to 10 feet outside bypass entrances and within bypasses at the Chandler Canal Fish Screen Facility in 2001. Bypass 1 = first intermediate bypass, Bypass 2 = second intermediate bypass, Bypass 3 = terminal bypass, Sep. Chamber Bypass = bypass from separation chamber – leading to the JEF.

Date	12/17/2001	12/17/2001	8/9/2001	8/27/2001	10/3/2001	9/28/2001	12/20/2001	12/21/2001	11/5/2001
Flow	317	400	503	600	692	854	1000	1200	1214
Bypasses									
Average Outside Bypass 1	0.60	0.58	1.13	0.75	0.70	0.95	0.95	0.48	1.05
Average Bypass 1	1.28	1.13	1.83	2.00	1.20	1.95	1.60	2.03	2.30
Average Outside Bypass 2	0.73	0.65	1.35	1.10	0.75	0.98	1.10	1.53	1.23
Average Bypass 2	1.40	1.18	2.23	2.30	2.05	2.35	1.78	2.15	2.25
Average Outside Bypass 3	0.68	0.58	1.28	1.05	0.83	1.30	1.10	1.40	1.10
Average Bypass 3	1.48	1.43	1.85	2.20	2.00	2.20	1.68	2.15	2.35
Average Sep. Chamber Bypass	2.45	2.50	2.50	5.25	2.40	2.35	2.35	2.65	2.50

Sensor Fish Device

During the low flow study in August 2001, 19 sensor fish device releases were completed. During high flow, 13 sensor fish device releases were made, 2 of which were not recovered. Pressure time histories indicate few conditions were observed that would be expected to result in injurious effects to fish passing through the Chandler Canal Screen Facility. Data from other sensor fish device studies was used to identify thresholds above which injury occurs. These thresholds were used as standards to compare to Chandler Canal data. These thresholds provide a general idea of how these physical forces relate to fish injury; however, it should be noted that site-specific conditions might affect these threshold values.

The acceleration vector magnitude data and its derivatives, jerk and velocity vector magnitude differential, indicate that conditions for injury to fish are minor in the Chandler Canal Fish Screen Facility relative to other areas where sensor fish devices have been deployed. Figure 17 shows an example of the gauge pressure trace of a sensor fish device deployed immediately upstream of the terminal bypass. All figures of sensor fish device data are presented in Appendixes A and C. The specific information regarding the sensor fish device deployments at low (503 cfs) and “normal” (1200 cfs) canal flows are presented below.

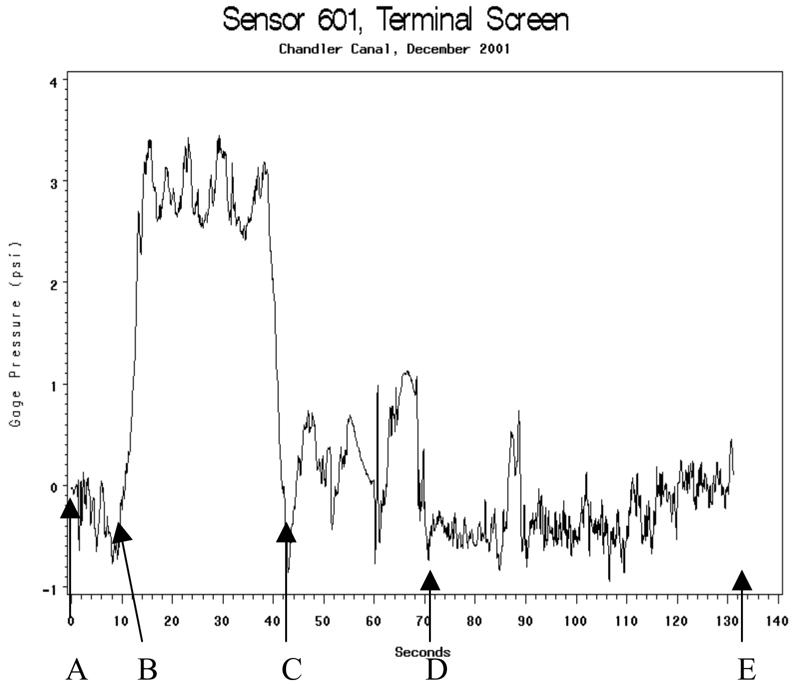

Figure 17. Example of a pressure trace from a sensor fish device deployed in the terminal bypass at the Chandler Canal Fish Screen Facility. A = release upstream of bypass entrance, B = entrance into the bypass pipe, C = entrance into the weir bow structure, D = entrance into the separation chamber, E = recovery.

Sensor Fish Device Results at a Canal Flow of 503 cfs

Few conditions were observed that would be expected to injure salmonids passing through the Chandler Canal Fish Screen Facility when the canal flow was 503 cfs. Plots of pressure and acceleration magnitude time histories in conjunction with cumulative distribution plots for jerk and velocity vector magnitude change over digital sampling periods for all sensor fish device low flow releases are shown in Appendix A. A table showing the time of occurrence and magnitude of the largest absolute values of jerk and velocity vector magnitude differential observed for each low flow sensor fish device release is located in Appendix B.

The pressure history of sensor fish releases is very useful for identifying the general location of the sensor fish device as a function of time while the acceleration vector magnitude indicates the degree of turbulence the sensor fish device is experiencing. For the sensor fish device released at the Terminal Screen bypass, the “injection” point into the water occurs at approximately 1 to 2 seconds. The sensor fish device travel time through the bypass pipe to the weir box was approximately 45 seconds.

Intermediate bypass results show the injection point into the water to occur at approximately 1 to 2 seconds. Travel time from point of injection through the bypass pipe to the intermediate weir box was approximately 90 seconds.

Weir box trials showed relatively few physical conditions that would be expected to result in deleterious effects on passing smolts. Pressures were low and sensor fish devices were recovered from the tank at approximately 1 minute in all but 1 case (Sensor 504, Rep 1), which continued to the fish facility building. Results for this sensor gave the most frequent jerk values greater than 2000 ft/sec^3, which occurred following its passage through the weir box.

Low pressures were observed from the data for the sensor fish device that traveled from the weir tank to the Juvenile Evaluation (JEF) building. The sensors for all three trials were recovered at 90 to 95 seconds. The LOEL value of 3.7 ft/sec was exceeded in Sensor 601 at the entrance to the bypass pipe and during the time period the sensor arrived on the separator in the JEF building.

Results observed from the sensor fish devices that went from the JEF building to the river indicate that there was a higher percentage of jerk values over 2000 ft/sec^3, approximately 0.65%.

Exceedance of jerk values > 2000 ft/sec^3 was less than 0.38% for all low flow results. Maximum jerk values were observed in sensor fish devices passing from the JEF building to the river and from the weir tank to the JEF building.

Higher values of velocity vector magnitude differential occurred within the same time periods as high values of jerk. This is expected since both are derived from tri-axial acceleration values. The exceedance of velocity vector magnitude differential greater than the lowest observed effect level (LOEL) of 3.7 ft/sec was less than 0.001% for all low flow results. Values exceeding the LOEL of 3.7 ft/sec were observed in 3 sensor fish device trials, 2 in data obtained from the weir tank to fish facility building, and 1 from data obtained from the sensor that traveled from the JEF building to the bypass outfall in the Yakima River (Figure 18).

Based on the sensor fish device data collected when canal flows were 503 cfs and water from the bypasses was passing underneath the weirs, it appears that this configuration is suitable for safe fish passage.

Sensor Fish Device Results at a Canal Flow of 1200 cfs

Pressure time histories indicate few injurious effects would be encountered in the Chandler Canal Screen Facility. The acceleration vector magnitude data and its derivatives, jerk and velocity vector magnitude differential, indicate that conditions for injury to fish are minor in the Chandler Canal Fish Screen Facility.

Plots of pressure and acceleration magnitude time histories in conjunction with cumulative distribution plots for jerk and velocity vector magnitude change over digital sampling periods for

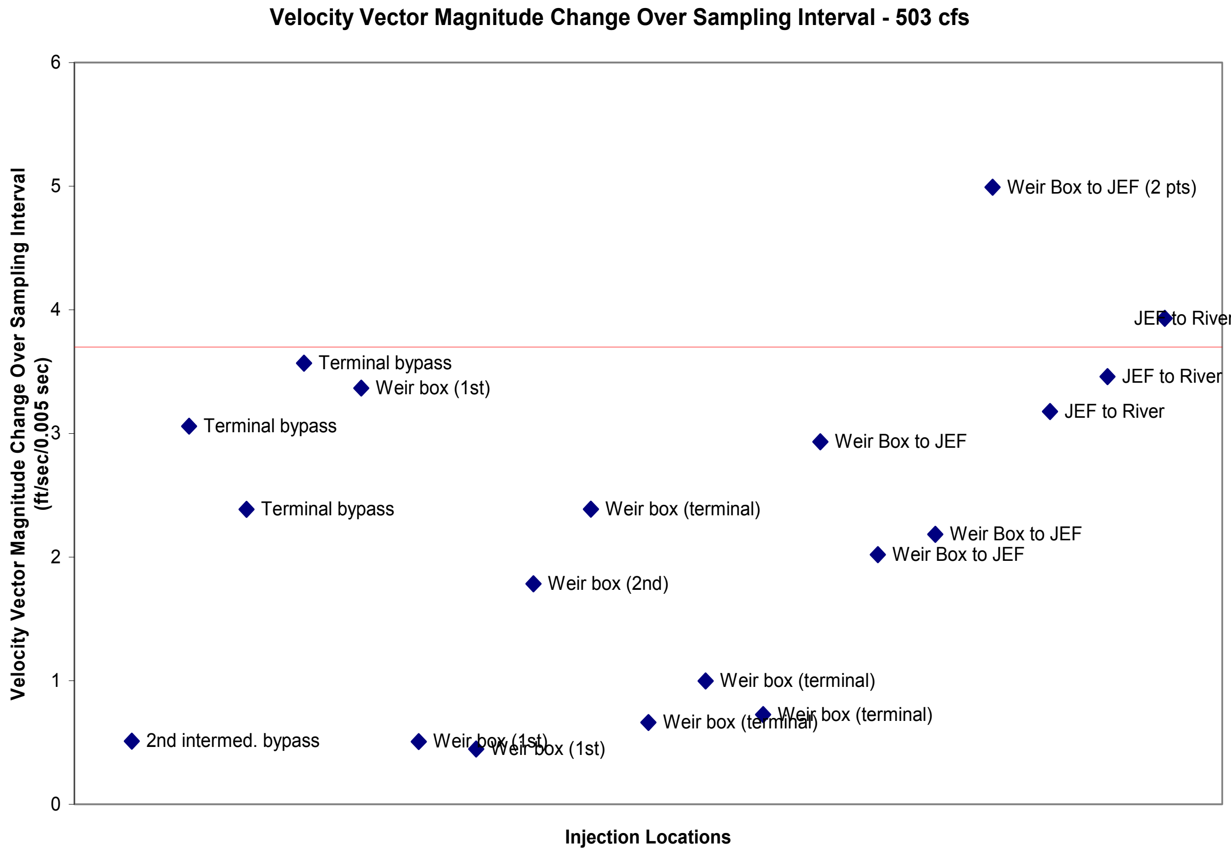

Figure 18. Maximum values of velocity vector magnitude change over sampling interval (ft/0.005 sec) experienced by the sensor fish device in various portions of the Chandler Canal Fish Screen Facility on August 9, 2001, when canal flow was 503 cfs. Values in excess of higher than 3.7 (denoted by the red line) are considered to have the potential to injure salmonid smolts.

all sensor fish device high flow releases are shown in Appendix C. A table showing the time of occurrence and magnitude of the largest absolute values of jerk and velocity vector magnitude differential observed for each high flow sensor fish device release is located in Appendix D.

For the sensor fish device released at the Terminal Screen bypass, the "injection" point into the water occurs at approximately 1 to 2 seconds. The sensor fish device travel time through the bypass pipe to the weir box was approximately 30 seconds, and was quite uniform for the 3 terminal screen samples. Higher flows appear to shorten the period in the bypass pipe by approximately 15 seconds.

Intermediate Screen results show the injection point into the water to occur at approximately 1 to 2 seconds. Travel time from point of injection through the bypass pipe to the intermediate weir box was approximately 60 to 70 seconds. Time in the bypass pipe is approximately 20 seconds shorter than during low flow. Potential injury conditions are few.

Results observed at the 1st Screen show that travel time from point of injection through the bypass pipe to the intermediate weir box was approximately 125 seconds. Potential injury conditions are few.

Weir box effects are similar for the three box locations (1st Weir, Intermediate Weir, and Terminal Weir). Pressure histories indicate the sensors going to an approximate depth of 5 to 6 feet as they traveled over the weir into the weir tank. Intermediate Weir (Sensor 501) results indicate that the LOEL value of 3.7 ft/sec was exceeded during its passage into the underground pipe that leads to the building facility.

Low pressures were observed from the data for the sensor fish device that traveled from the weir tank to the fish facility building. However, jerk values exceeding 2000 were more frequent in this vicinity.

Exceedance of jerk values >2000 ft/sec^3 was less than 0.8% for all high flow results. Maximum jerk values were observed for two terminal screen samples during the entry of the sensor fish device into the underground pipe leading from the terminal screen to the weir box. Jerk values greater than 2000 ft/sec^3 were most abundant in results observed from the Terminal Screen series and the results for devices traveling from the weir tank to the fish facility building.

The exceedance of velocity vector magnitude differential greater than the LOEL of 3.7 ft/sec was less than 0.001% for all high flow results. Values exceeding the LOEL of 3.7 ft/sec were observed in 3 sensor fish device trials, 2 at the terminal screen and 1 from the intermediate weir trial. Exceedance values were observed for two terminal bypass samples during the entry of the sensor fish device into the underground pipe leading from the terminal screen to the weir box (Figure 19). The information obtained from the intermediate weir trial indicate that the exceedance occurred following the passage over the weir box, when the sensor was traveling through a pipe to the JEF building.

Fish Entrainment Data Review

In general, survival of juvenile salmonids through Chandler Canal was good (mean survival rate in 2001, all salmonids combined, was 85.9%). However, juvenile salmon and steelhead generally experienced higher canal survival when flows in Chandler Canal were higher, date was earlier, and water temperature was lower. Survival rates for all salmonids combined in Chandler Canal were positively correlated with canal flow in 2001 (Figure 20). In 2001, it appeared that there was some threshold between canal flows of 500 and 550 cfs. The mean survival rate of all salmonids in the canal in 2001 was 47.2% when canal flows were less than 500 cfs and 88.7% when canal flows were 548 cfs or higher.

While we did not have canal velocity data to compare to canal survival data, we assume that when the canal is operated and configured in a consistent manner, there is a positive relationship between canal flow and canal velocity. We do not have enough data to separate the effects of canal flow and canal velocity on salmonid survival through the canal, however, some of the structural modifications that are discussed in the computational fluid dynamics modeling section

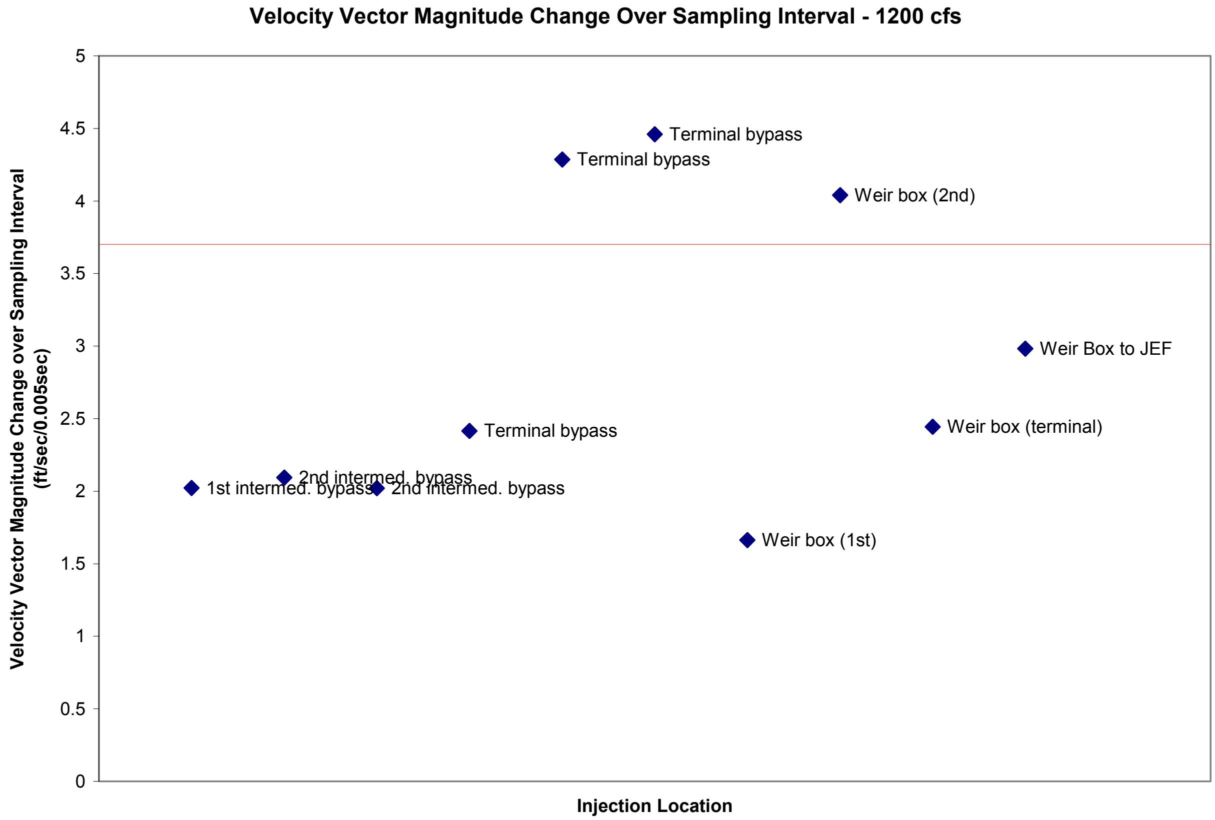

Figure 19. Maximum values of velocity vector magnitude change over sampling interval (ft/0.005 sec) experienced by the sensor fish device in various portions of the Chandler Canal Fish Screen Facility on December 21, 2001, when canal flow was 1200 cfs. Values in excess of higher than 3.7 (denoted by the red line) are considered to have the potential to injure salmonid smolts.

(below) may increase velocity through the forebay, which we would expect to result in increased survival. If the Chandler Canal were to be regularly operated at low flows (e.g., 600 to 800 cfs), then structural modifications to the entire canal between the headworks and the fish screens, which would increase velocity, would be expected to increase the survival of juvenile salmonids passing through the canal (please see the recommendations section for more on this).

Survival of salmonids also tended to decrease as the migration season progressed and as water temperature increased in 2001 (Figure 21 and Figure 22). Figure 23 shows the interactions between date, canal flow, and water temperature for 2001. It is apparent that these variables are not independent, making it impossible to fully isolate the effects of each of these variables on survival within the canal (e.g., as date increases so does temperature). What is clear is that as the season progresses and water temperature increases, salmonid survival in Chandler Canal declines.

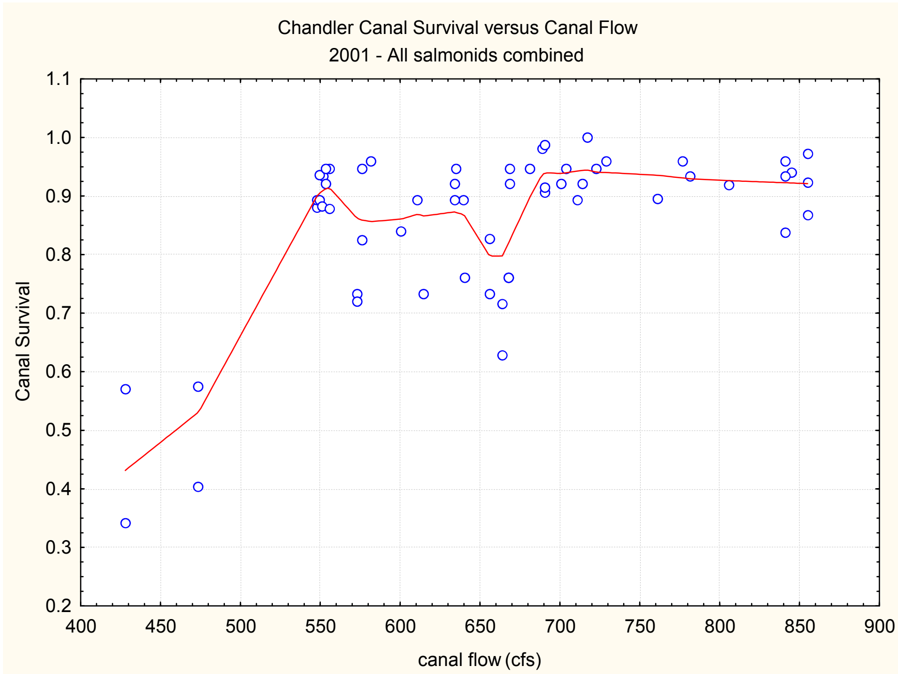

Figure 20. Estimated survival of all salmonids combined (coho, spring chinook, and fall chinook salmon) in Chandler Canal versus canal flow (cfs) in 2001. The red fitted line represents a Lowess smoothing (robust locally weighted regression). Data from the Yakama Nation.

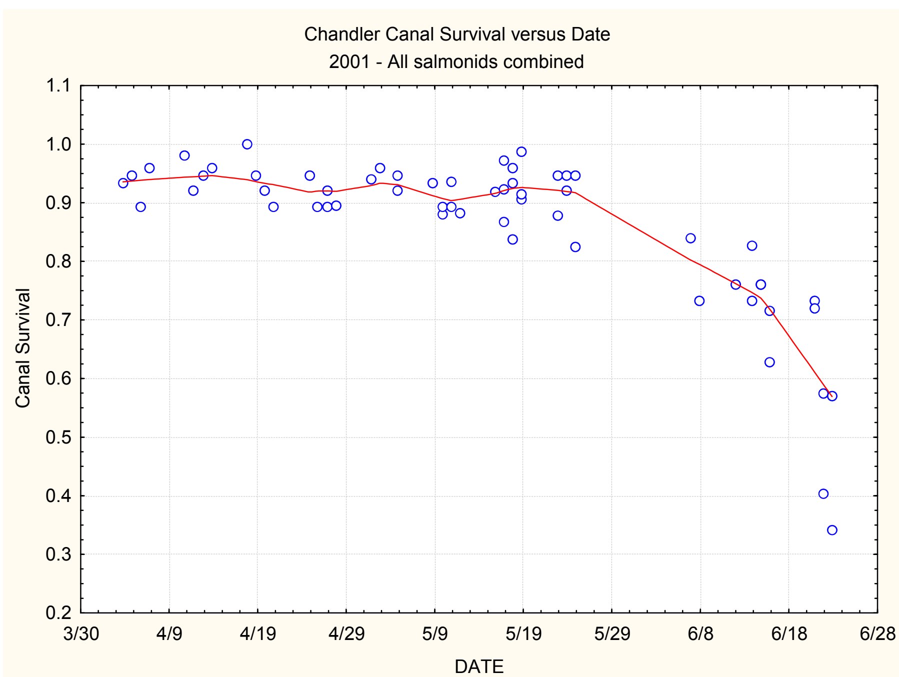

Figure 21. Estimated survival of all salmonids combined (coho, spring chinook, and fall chinook salmon) in Chandler Canal versus date in 2001. The red fitted line represents a Lowess smoothing (robust locally weighted regression). Data from the Yakama Nation.

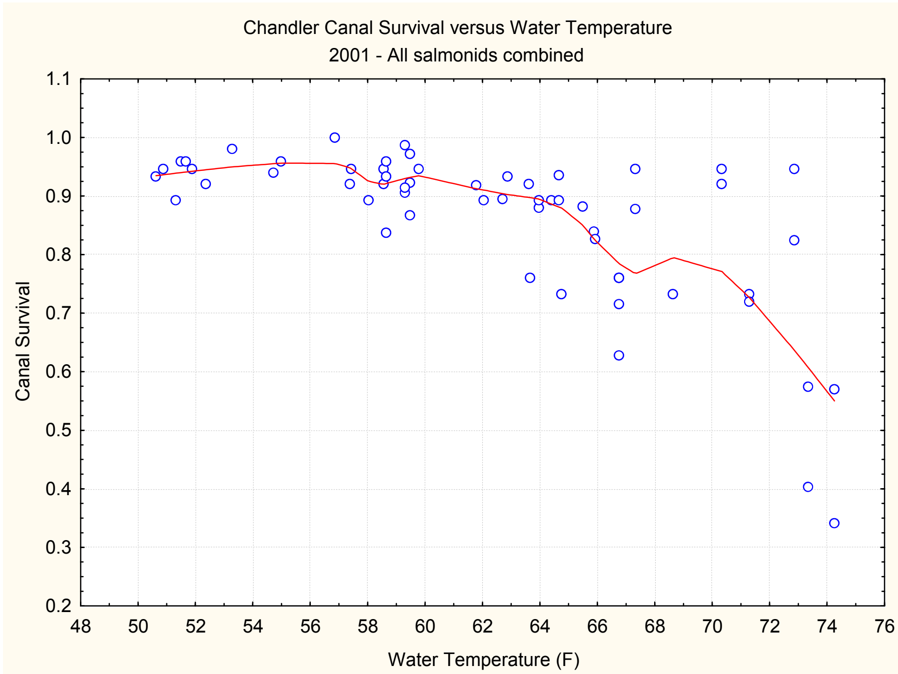

Figure 22. Estimated survival of all salmonids combined (coho, spring chinook, and fall chinook salmon) in Chandler Canal versus water temperature (in the JEF) in 2001. The red fitted line represents a Lowess smoothing (robust locally weighted regression). Data from the Yakama Nation.

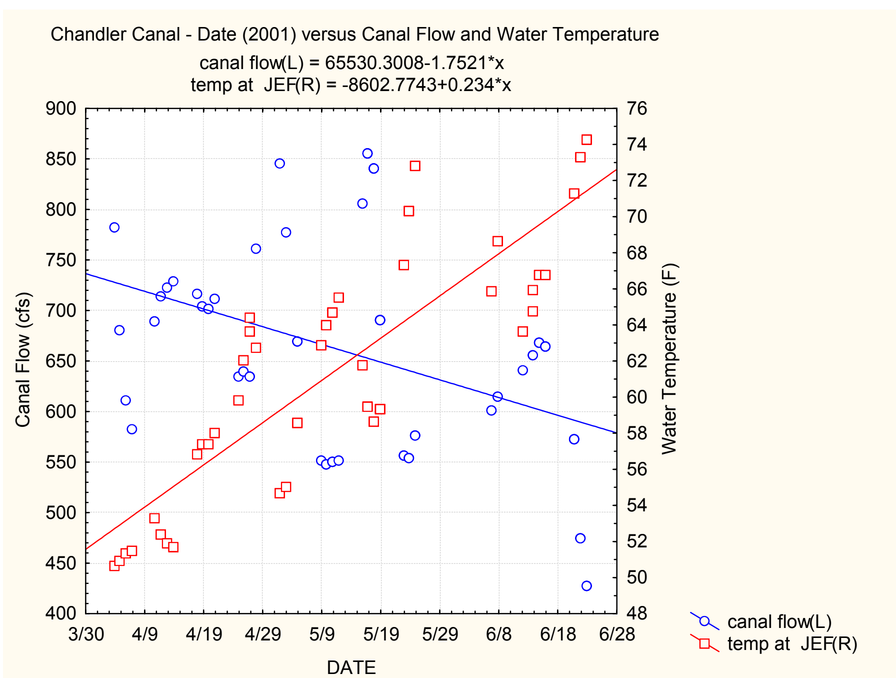

Figure 23. Chandler Canal flow (cfs) and water temperature (in the JEF) versus date in 2001. Lines were fitted to the data using general linear models.

Computational Fluid Dynamics Modeling

The numerical model created for the Chandler forebay is an unstructured mesh composed of about 1 million cells, and this allowed the specification of flow for each drum screen and fish bypass (Figure 24). The model included the sediment as it was surveyed on December 13, 2001 (Figure 25), the ecology blocks, and the drum screens were represented as porous baffles with a porosity of 30%. The forebay elevation for all simulations was 630.35 feet and the flow depth at the drums screens was 9.5 feet (67% submergence; see Appendix E for more information on screen submergence).

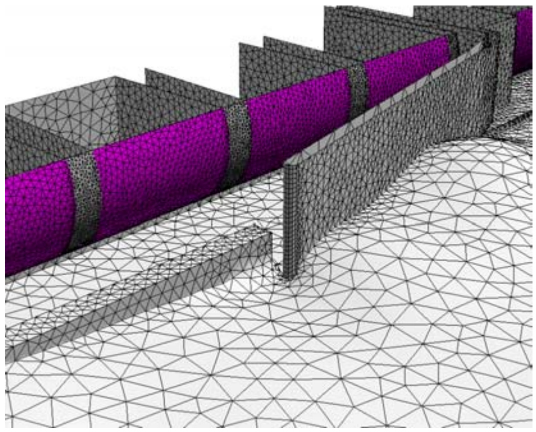

Figure 24. View of computational mesh, including the training wall, ecology blocks, and drum screens (purple). In the simulations, a baffle was included between the ecology blocks and the training wall.

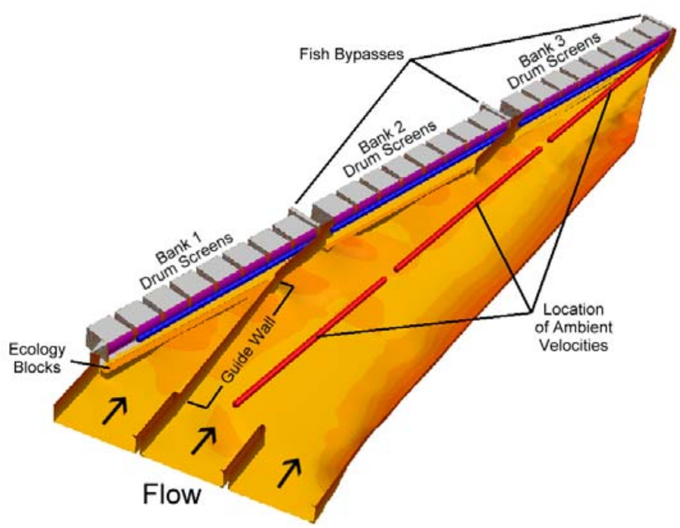

Figure 25. Overall extent of the computational domain and features of the Chandler Fish Handling Facility used in the simulations. The sediment in the forebay was surveyed on December 13, 2001, and included in the simulations.

Validation Simulation

Point samples of simulated velocity coincident with field-measured velocities were extracted from the numerical model. These data for sweep and approach velocities are compared in Figure 26 and Figure 27, respectively. The modeled approach and sweep velocities closely followed the field-measured velocities at the 0.2 depth locations, although the modeled sweep velocities were consistently low and approach velocities consistently high at the upper elevation. The reason for this discrepancy is likely due to the effects of the porosity board settings. The flow through the drum screens is controlled to some extent by porosity boards behind the drum screens; the effect of the porosity boards, that is, the uneven vertical distribution of flow through the drum screens was not included in the model. Futures studies should include validation of models that includes porosity boards if that level of detail in model results is deemed necessary. For these initial simulations (which were not intended to be exact quantifications of velocities), this overall level of agreement was deemed adequate.

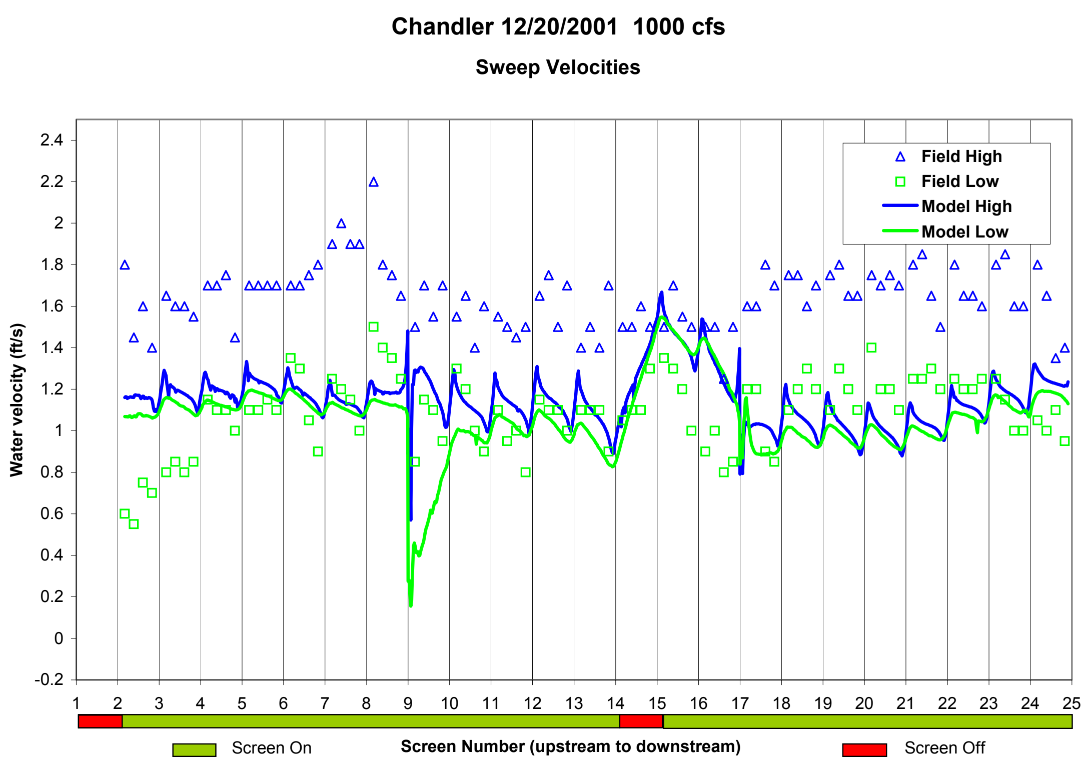

Figure 26. Measured and modeled sweep velocity on a vertical plane 4 inches from the drum screens. The "High" and "Low" measurements denote the 0.2 and 0.8 depths, respectively.

Flow Scenarios

New boundary conditions for each scenario were applied to the model as specified in Table 2. The flow split was the same as was used for the validation simulation for cases without a guide wall. For cases with a guide wall, the proportional flow split between the second and third bank of drum screens was used, that is, 46% and 54%, respectively. Simulation velocities

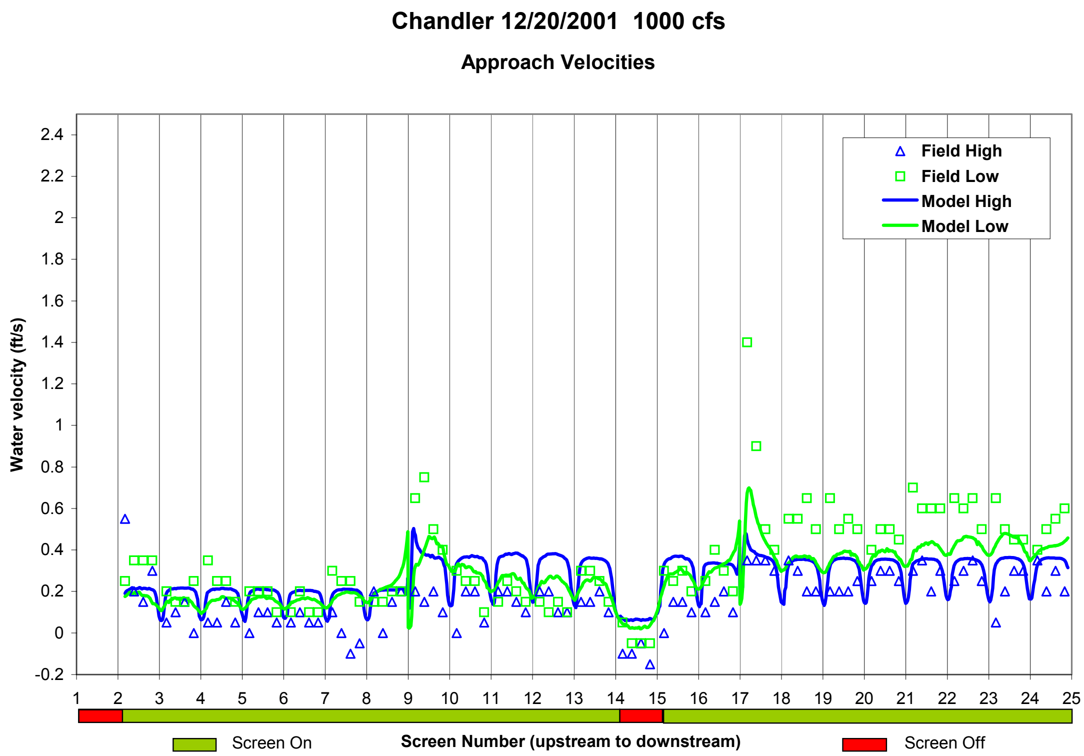

Figure 27. Measured and modeled approach velocity on a vertical plane 4 inches from the drum screens. The "High" and "Low" measurements denote the 0.2 and 0.8 depths, respectively.

were extracted from the numerical model at the 0.6 depth to capture the average flow velocities near the screens, and graphics created plotting sweep, approach, and "ambient" flow velocities in the forebay. The 0.6 depth was used here as an overall average as the effects of the porosity boards were not included in the numerical model. The ambient velocity (as illustrated by the red lines in Figure 25) was taken from the center of the forebay at the elevation of 628.45 feet (0.2 depth on screens).

As shown in the validation simulation, however, the numerical model, which did not include the porosity boards behind the drum screens, did not replicate the vertical flow distribution through the drum screens. Consequently, the results near the drum screens should be viewed qualitatively, rather than quantitatively.

Case 1 and 2 – 1200 cfs Without and With Holes in Training Walls

Cases 1 and 2 were used not only to simulate the forebay flow field for a discharge of 1200 cfs (Figure 28), but also to test the effect of adding flow-through areas ("holes") in a portion of the training wall (Figure 29). Flow-through areas (1 foot wide) were added into the training wall from elevations of 621.74 to 624.19 feet and from 627.0 to 628.7 feet. The desired effect of adding the flow-through areas was to reduce the approach velocity at screen 9, where field measurements of velocity have measurements that violate approach velocity criteria. Figure 30 shows the changes in near screen velocities and the ambient flow at 0.6 depth that

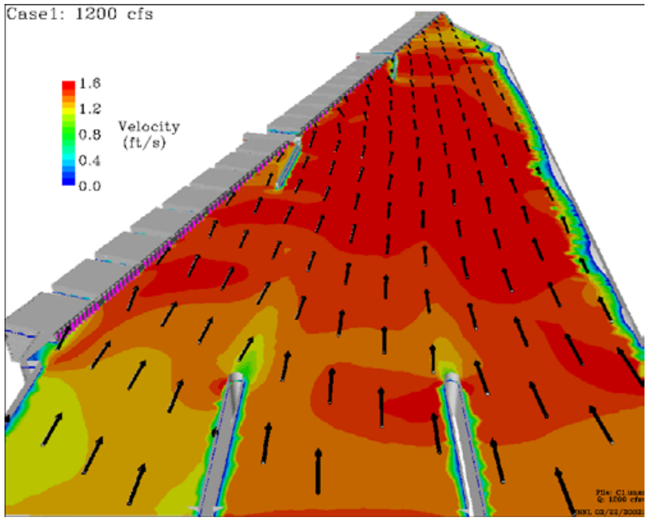

Figure 28. Case 1 velocities at the 0.2 depth.

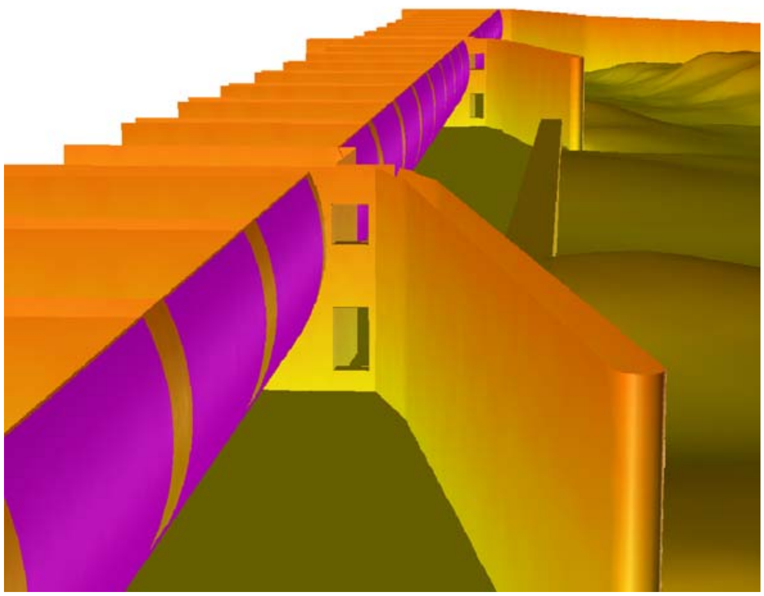

Figure 29. Geometry used for Case 2, with holes in the downstream edge of the training walls.

might be expected if holes were created in the downstream end of the training wall. As expected, there is little change in the ambient velocities. The greatest effect is found at the drum screens in proximity to the holes. Near screen 9, just downstream of the training wall holes, the desired effect occurred, that is, the approach velocities decreased and the sweep velocity was increased (Figure 31 and Figure 32). An added benefit was the low velocity area in the lee downstream of the training wall, another possible predator habitat, was reduced in size although not eliminated. Note that the improvement in flow field, that is the decreased approach and increased sweep velocities, at screen 9 was not replicated at screen 17. One assumption made was in the numerical model, that the flow through the fish bypass was unchanged. This may not be correct, especially at the downstream training wall. In this location, the simulation had little

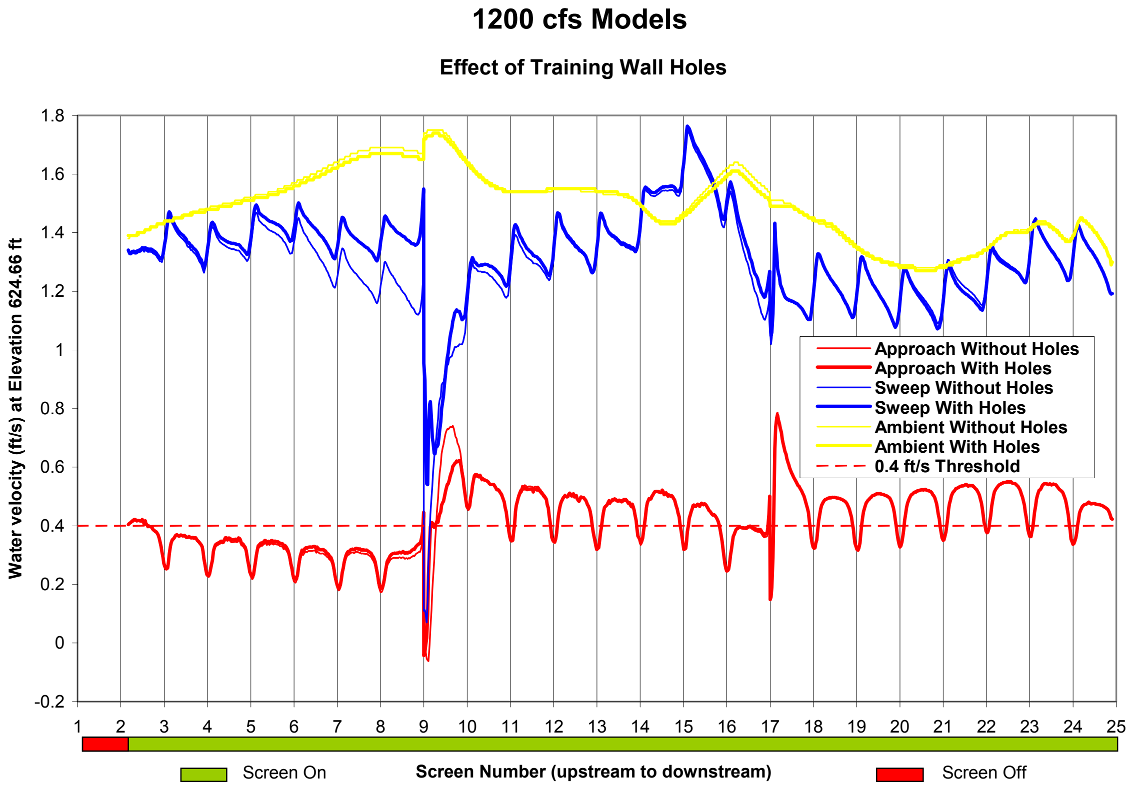

Figure 30. Approach and sweep (0.6 depth), and ambient (0.2 depth) water velocities at the Chandler Canal Fish Screen Facility without and with holes in the intermediate bypass training walls (Case 1 and Case 2, respectively).

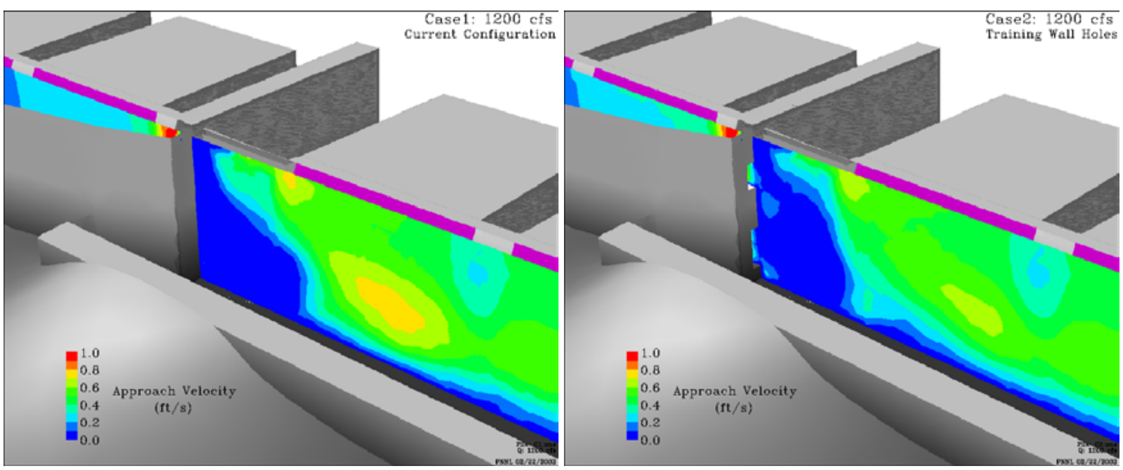

Figure 31. Approach velocities for simulations without (Case 1) and with (Case 2) holes in the training wall.

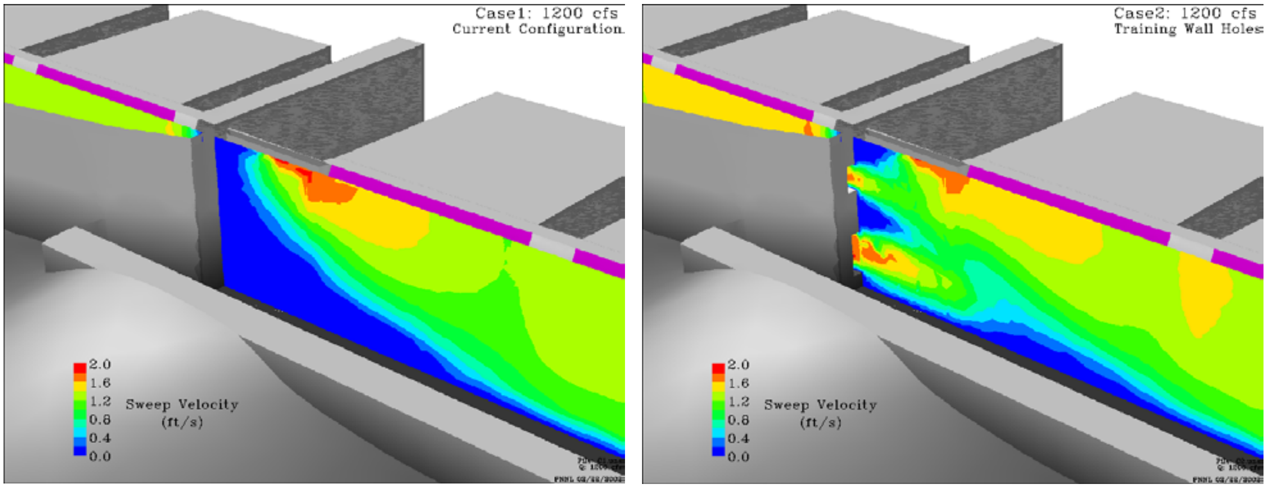

Figure 32. Sweep velocities for simulations without (Case 1) and with (Case 2) holes in the training wall.

water passing through the holes in the training wall. In reality, one would expect that the amount of water moving into the fish bypass would be reduced, with water flowing through the holes and reducing the higher-than-desired impingement velocities found on screens 9 and 17. Consequently, in the above discussion, the focus was on the changes in flow field between screens 8 and 9. The attached computer animation (cases1&2.avi) illustrates the modeled effects of cutting holes in the training wall immediately upstream of screen 9. Note the reduction in approach velocity and concomitant increase in sweep velocity after the holes are cut in the training wall.

The addition of the holes in the training walls appears to be a reasonable solution to the high approach velocity areas observed on screens 9 and 17. The effect of reducing these high approach velocity areas on fish passage would be a reduction in the likelihood of small salmonids becoming impinged on the drum screens. In addition, the increased sweep velocities should reduce delay in the screen forebay and guide fish to bypass openings more quickly.

Case 3 – 900 cfs

The Case 3 simulation results show the lower velocities resulting from reduced flow through the forebay (Figure 33 and Figure 34). The reduction of flow from 1200 to 900 cfs reduced the ambient flow about 0.3 to 0.4 ft/sec, the approach velocities near the screens were reduced by 0.1 to 0.2 ft/sec, and the sweep velocities were reduced by 0.3 to 0.4 ft/sec, depending on location. The attached animation (case3.avi) provides a visual representation of these data.

Cases 4 and 5 – 700 cfs Without and With a Guide Wall Blocking Screens 1 to 8

Cases 4 and 5 show the effect of reducing the area through which a fixed flow, 700 cfs, passed (Figure 35 and Figure 36). As expected, reducing the cross-sectional area increased the water velocities. Figure 37 plots the difference in sweep and approach velocity and the ambient flow magnitude for Case 4 and Case 5. This plot shows that the ambient velocity, that is, the

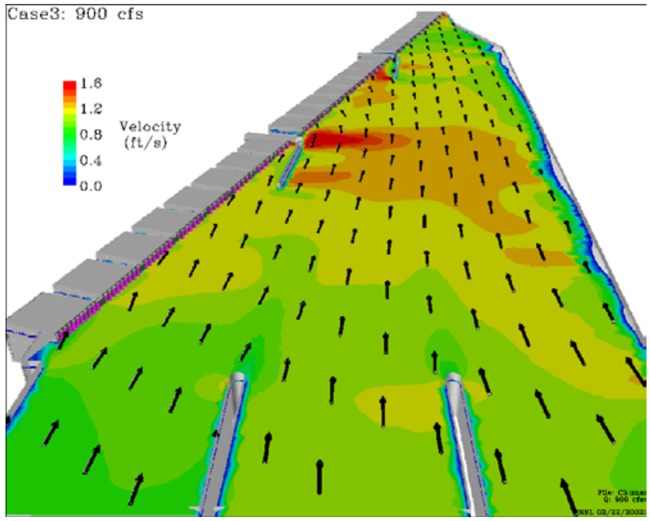

Figure 33. Case 3 velocities at the 0.2 depth.

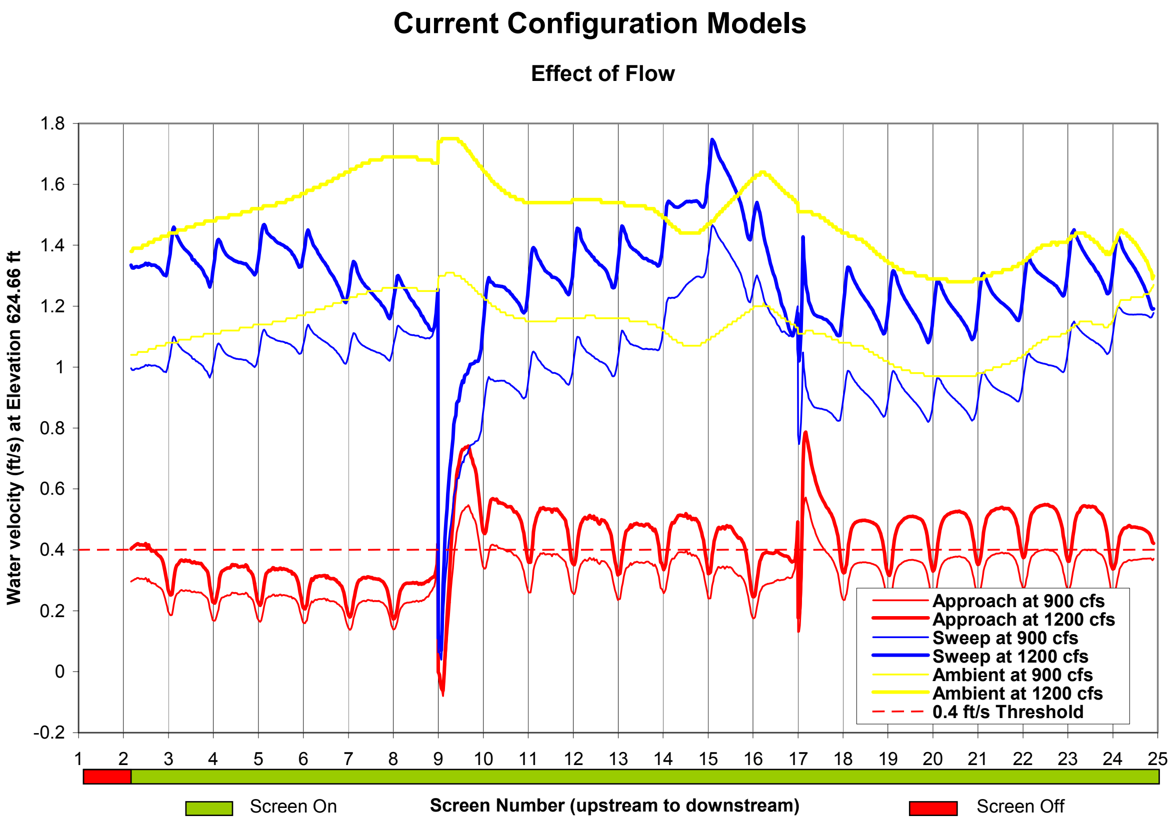

Figure 34. Water velocities at discharges of 900 and 1200 cfs (Case 3 and Case 1, respectively).

velocity in the mid-forebay was increased about 0.23 ft/sec, the sweep velocities in front of the drum screens increased about 0.2 ft/sec, and the approach velocities increased by about 0.1 ft/sec. The attached animation (case4&5.avi) provides a visual comparison of these two scenarios.

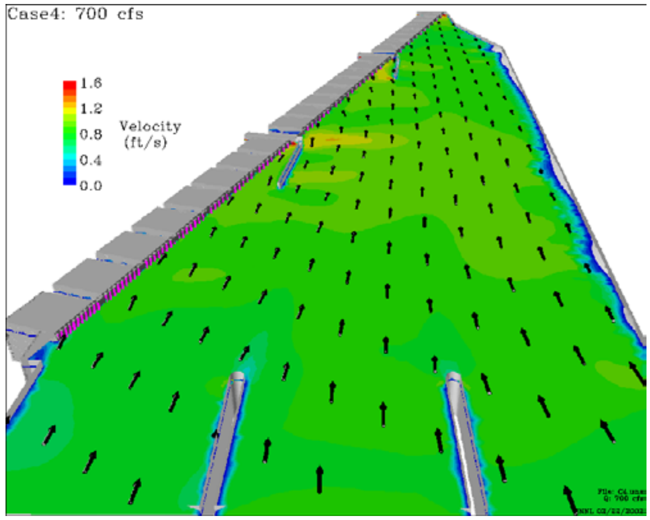

Figure 35. Case 4 velocities at the 0.2 depth.

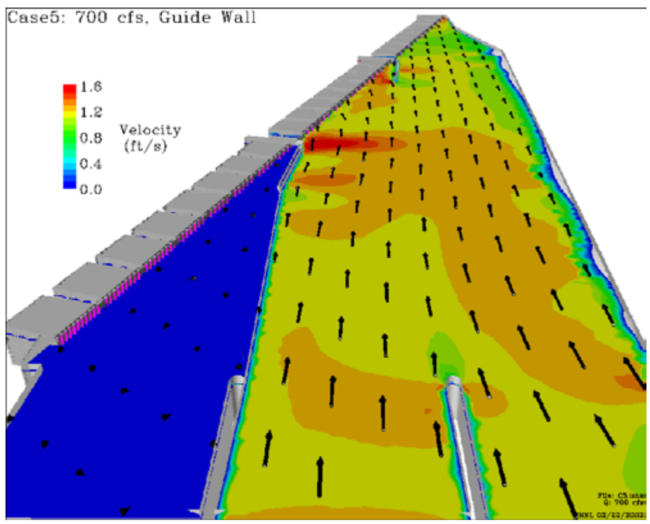

Figure 36. Case 5 velocities at the 0.2 depth.

The addition of this temporary guide wall would benefit fish passing through the Chandler Canal at low flows (about 700 cfs or lower), by increasing ambient velocities in the forebay, and increasing sweep velocities along the screens, without a major increase in approach velocities.

Case 6 – 500 cfs With a Guide Wall Blocking Screens 1 to 8

Case 6 had a much lower total flow, 500 cfs, although the forebay elevation was assumed to be controlled by downstream structures (at the old screen site) to an elevation of 630.35 feet. As expected, the simulated forebay velocities were lower than Case 5, however, the velocities were only slightly less than those of Case 4 (Figure 38 and Figure 39), showing that similar forebay velocities may be maintained at lower flows if total flow area is reduced by the construction of a guide wall. The attached animation (case6.avi) provides a visual representation of the flow patterns at 500 cfs canal flow with the guide wall in place.

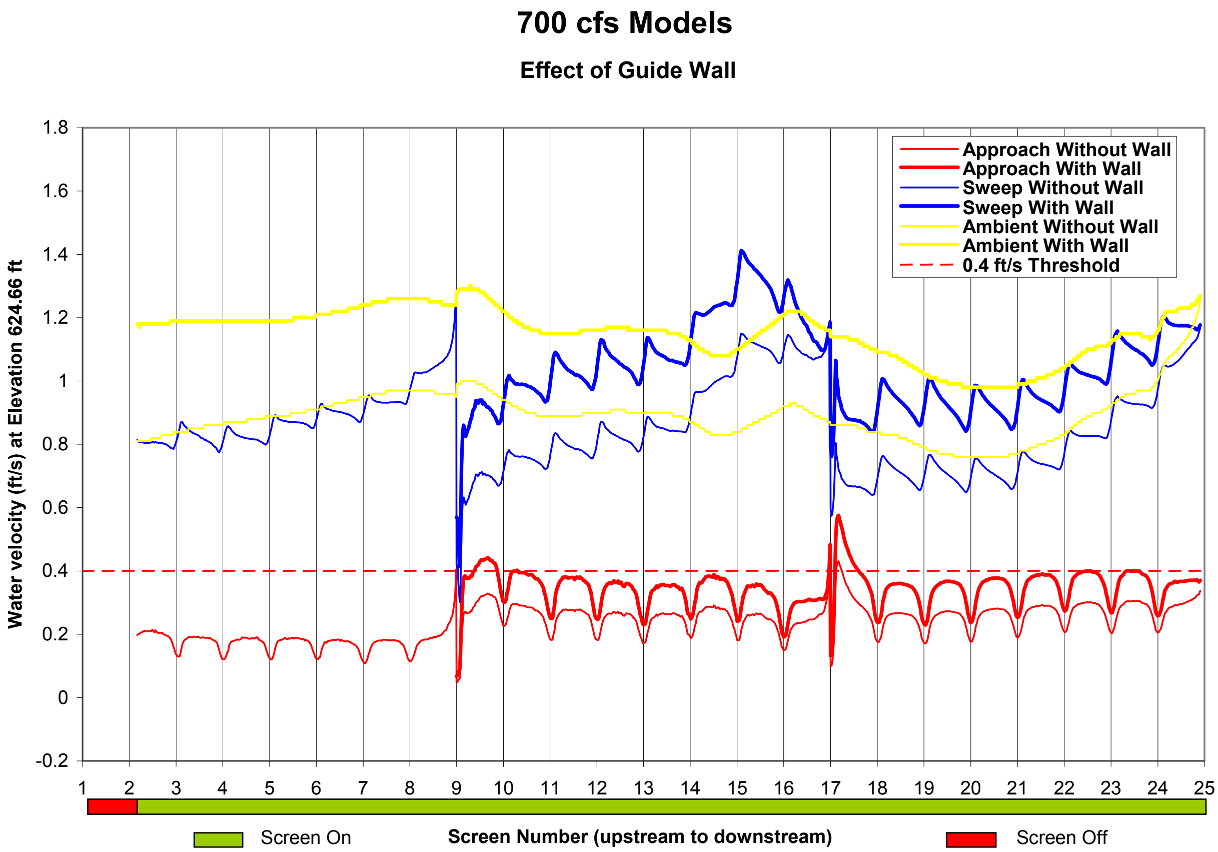

Figure 37. Changes in water velocity due to adding a guide wall for a discharge of 700 cfs (Case 4 and Case 5).

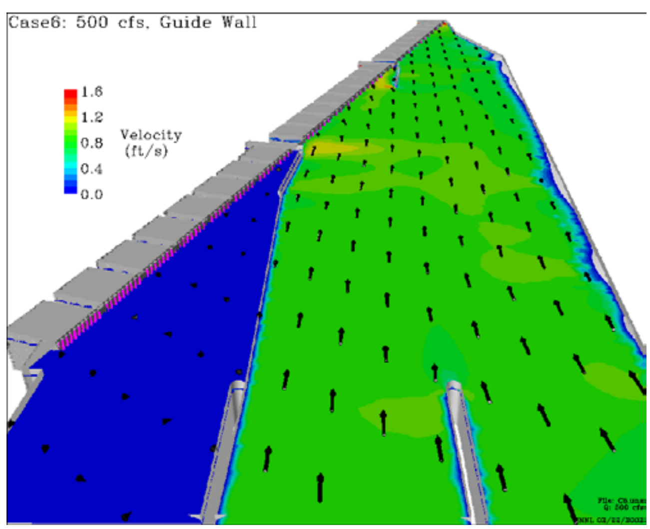

Figure 38. Case 6 velocities at the 0.2 depth.

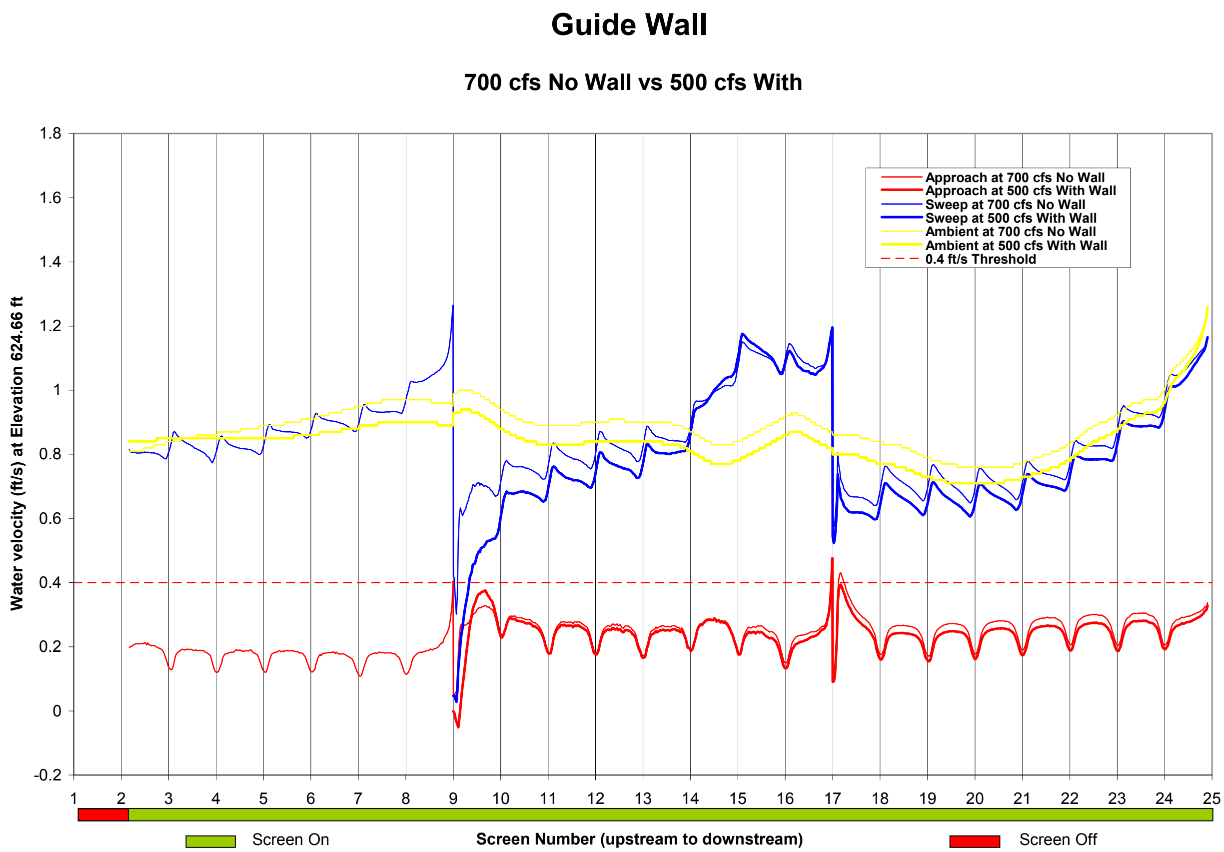

Figure 39. Change in overall velocity for 500 cfs with an added guide wall, and 700 cfs in the current forebay configuration (Case 6 and Case 4, respectively).

The ambient velocities through various portions of the forebay were compared among the scenarios modeled. A computer animation (transects.avi) of these cross-sectional velocities shows the water velocity magnitude and direction in comparison to the baseline of 1200 cfs (Case 1). The baseline condition (1200 cfs) is shown for reference as the black arrows while the other scenarios are presented in color. This animation shows that the cross-sectional velocities in the screen forebay tend to increase as canal flow increases. In addition, it shows that the velocities at a canal flow of 700 cfs are higher when a guide wall is in place (Case 4) than when it is not (Case 5). This increase in ambient velocities would be expected to reduce the time that juvenile salmonids spend in the forebay, which should result in increased survival.

Discussion

Water Velocities

Under the majority of the conditions we evaluated, the water velocities were acceptable in reference to the NMFS criteria. The exceptions to this were generally associated with two factors. First, the screens immediately downstream of the intermediate bypass training walls (screens 9 and 17) often showed approach velocities in excess of the 0.4 ft/sec criteria. The second location where we often observed excessive approach velocities was at the deeper (0.8 of depth) measurement points along the lower eight screens (screens 17 to 24). This effect was likely due to the setting of the porosity boards. The larger gap below the porosity boards downstream of the lower eight screens effectively pulled more water through the lower portions of these screens.

These high approach velocities might provide problems for very small juvenile salmonids (e.g., subyearling chinook salmon), as many salmonids tend to migrate past structures low in the water column during the daytime. While the approach velocities near the bottom may help reduce the wear and tear of silt accumulations on screen seals by increasing velocity near the bottom of the screens, they could also result in impingement of small juvenile salmonids or lamprey. While the larger gap size (22 inches) under the porosity boards behind the lower eight screens (17 to 24) passes more flow, and tends to increase sweep velocity along the upper 16 screens, aiding in leading fish toward the bypasses, it does tend to produce approach velocity values that exceed the NMFS fish protection guidelines.

Sweep and approach velocities generally increased with increasing canal flow. There were some exceptions to this however. The most perplexing was the discrepancy between the two series of measurements that were made around the 1200 cfs canal flow. The high approach velocities seen at the 1214 cfs level may have been due to some electrical interference with the current meter, but this is unlikely as it was the same equipment that was used without interference on all the other surveys. It may also be that some modifications were made to the porosity boards or other structural features that we did not detect. It is worth noting that the velocity profiles generated on November 5, when the canal flows was 1214 cfs, were very similar to those measured on June 15, 2000, when canal flows were 1332 cfs. The mean approach velocities were essentially the same and the areas where approach velocities were high (screens 9 and 17) were also the same.

Approach velocities in the separation chamber often exceeded the NMFS criteria of 0.4 ft/sec. Plans are in place, however, to replace the two existing screens with four new ones. This increase in cross-sectional area should effectively reduce approach velocities in a linear relationship to the cross-sectional screen area. In other words, if the percent open area and discharge (cfs) through the screens remains the same, a doubling of the screen area should reduce the mean approach velocity by 50%. With the turbulent flow that exists in the separation chamber, there still may be a few areas where approach velocities exceed criteria, but the mean should be reduced to a level that meets NMFS approach velocity criteria.

Sensor Fish Device

The results from the deployment of the sensor fish devices throughout the Chandler Canal Fish Screen Facility indicated that most areas of the facility do not present hydraulic conditions that would be expected to kill or injure migrating salmonids. However, there were a few locations where data suggested that some potential for fish injury existed under the conditions we evaluated. Under low flow conditions, one of the deployments (the weir box to the JEF and the JEF to the bypass outfall in the river) indicated the velocity vector magnitudes were slightly above the range that has been observed to result in injury to smolts. The bypass outfall also showed evidence of surging (Figure 40).

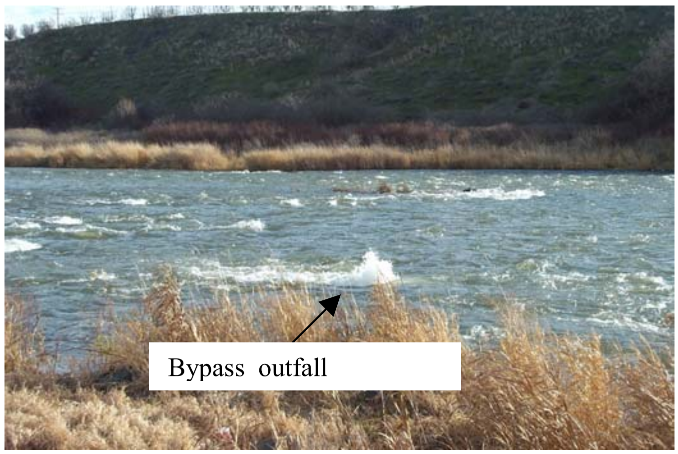

Figure 40. Chandler Canal Fish Screen bypass outfall in the Yakima River. Surging is evident in the center of the photo.

This surging would be expected to be reduced by the installation of an air vent in the bypass pipe between the JEF and the bypass outfall. The other potentially injurious conditions were observed under the 1200 cfs canal flow in the terminal bypass. It appeared that there were some conditions present between the terminal bypass entrance and the weir box that created larger than average changes in pressure and velocity vector magnitude. In addition, two of the sensor fish devices that were deployed at 1200 cfs were not recovered. This may indicate that there are some obstructions or other conditions in the bypass that were capable of entrapping inflexible fish-sized objects. However, the BOR did inspect the bypass system, inside the bypass pipes, the weir downwells, and between the separation chamber and the JEF. Although they attempted to have a robotic camera collect video inside the bypass pipe from the JEF to the bypass outfall in the Yakima River, they were not able to fully inspect this pipe (K. Puckett, BOR, personal communication). There is a possibility that the missing sensor fish devices were not retained on the separator in the JEF – and passed undetected to the Yakima River.

Fish Entrainment Data Review

Higher canal flows and earlier dates were correlated with higher salmonid survival in Chandler Canal between the headworks and the JEF. As McMichael and Johnson (2001) pointed out, the combination of higher ambient and sweep velocities would be expected to allow fish to negotiate their way through the screen facility and into the bypass system. Also, the later in the season a smolt passes through the facility, the greater chance that it might be exposed to predation for several reasons. First, predators are likely to be more abundant later in the migration season as species like smallmouth bass and northern pikeminnow migrate downstream after spawning. Second, the number of potential prey items decreases toward the end of the smolt emigration season (after mid-May). Finally, as water temperature increases, so does the metabolic scope for activity in predator species—resulting in more rapid digestion, and thus a higher consumption rate per predator. As previously stated, the interactions between canal flow, date, and water temperature make it difficult to ascertain what portion of the reduced survival is due to each of these factors. It is clear, however, that as the season progresses, and the water temperature increases—survival of salmonids in the canal is impacted. It also appears that this effect is exacerbated by reduced canal flows. All of these factors would be consistent with a survival reduction related to the abundance, effectiveness, and metabolic rates of fish predators in the canal. Please see the Computational Fluid Dynamics modeling and reducing predator habitat sections below for discussion of possible ways to decrease the effect of predation on smolts migrating through this facility.

To address the concern that fish passing through the canal may be deleteriously affected by this passage route, the longer-term survival of fish that pass through the canal (alive) should be compared to the survival of fish that do not pass through the canal (i.e., the pass downstream over Prosser Dam). This evaluation would compare the survival (to McNary Dam) of groups of fish that migrated though the lower Yakima River during similar blocks of time, with the only difference between groups being whether they were detected in the Chandler JEF. This type of evaluation was beyond the scope of this study.

Computational Fluid Dynamics Modeling

There are consistent flow features in all simulations. Ambient velocities were consistently higher near the trash racks, although flow accelerated as the channel constricts near the most downstream fish bypass. A recirculation zone developed in the area downstream of the training walls. The volume of this recirculation zone was reduced and fragmented by the inclusion of holes in the training wall. Just downstream of these recirculation zones are screens 9 and 17. There were zones of high approach velocities on both of these screens (in field and modeled data). CFD model results also showed a consistent area of recirculation within the fish bypass in the same area where predators have been observed (McMichael and Johnson 2001).

The placement of holes in the training walls and the use of a temporary guide wall blocking off the upper 8 screens appear to be viable alternatives for the operation of the canal during low flows periods. The holes in the training walls may also benefit fish at all canal flows by reducing or eliminating the approach velocity "hot-spots" in front of screens 9 and 17. The guide wall placement resulted in increased ambient (forebay) and sweep (near screen) velocities that would be expected to reduce travel time and thereby increase survival of juvenile salmonids passing through the facility. See Recommendations, below, for more details.

These simulations show the utility of numerical models in predicting overall flow patterns resulting from changes in canal discharge and structural configuration. However, these initial flow simulations for the Chandler Fish Screen Facility should be used only as a qualitative tool for comparison of the overall impact to flow velocities for changes in total discharge. To be used as a quantitative tool, more validation data would be required, and the details of flow through the drum screens and past the porosity boards should be included in the numerical model. The outflow boundary conditions for the model were based on field measurements of velocities that were used to deduce the overall flow splits between the drum screen bays. The numerical model did not include the porosity boards downstream of the drum screens. The porosity boards cause an uneven vertical distribution of flow through the drum screen. If future simulations are needed to more accurately simulate flow velocities near the drum screens, it will be necessary not only to include these structures, but also to have field validation data to support the modeling effort.

Reducing Predator Habitat

McMichael and Johnson (2001) found that adult smallmouth bass inhabited the bypass entrances at the Chandler Canal Fish Screen Facility during the summer of 2000. CFD modeling results identified low velocity habitats within the entrances to the intermediate bypasses that would provide optimal foraging locations for predators. To reduce these probable foraging locations, a carefully engineered fillet of concrete could be contoured into these locations to reduce or eliminate the flow separation and hence the low velocity foraging habitats (Figure 41). In addition, an electrode array with cathodes on one wall and anodes on the other wall could be installed in the area where predators have been observed. These electrode arrays could be wired to allow for periodic application of an electrofishing rectifier and power source (portable generator). A periodic application of 400 V of 60 Hz pulsed direct current could narcotize predator fish in this region. The velocity in the bypass (approximately 2.0 ft/sec) would be expected to remove any narcotized predators downstream and into the JEF where they could be collected and sampled for gut contents. To minimize impacts on emigrating salmonids, the timing of the application of electrical current could be coordinated with periods when salmonid smolt passage was lowest, based on real-time sampling by the Yakama Nation in the JEF. A combination of increasing sweep and ambient velocities through the facility, especially when the canal flow is low (<700 cfs), and decreasing predator habitat and removing predators by activating an electrical field in areas where predators have been observed would be expected to increase survival of salmonids passing through the Chandler Canal Fish Screen Facility.

Recommendations

To address the few areas where approach velocities violate NMFS criteria within the Chandler Canal Fish Screen Facility, it would be helpful to further develop the computation fluid dynamics model to better identify possible solutions. The placement of holes in the intermediate bypass training walls shows promise for alleviating much of this approach velocity problem. In addition, setting the porosity boards to provide a smaller gap near the forebay floor is recommended to reduce the high approach velocities near the bottom in front of screens 17 to 24.

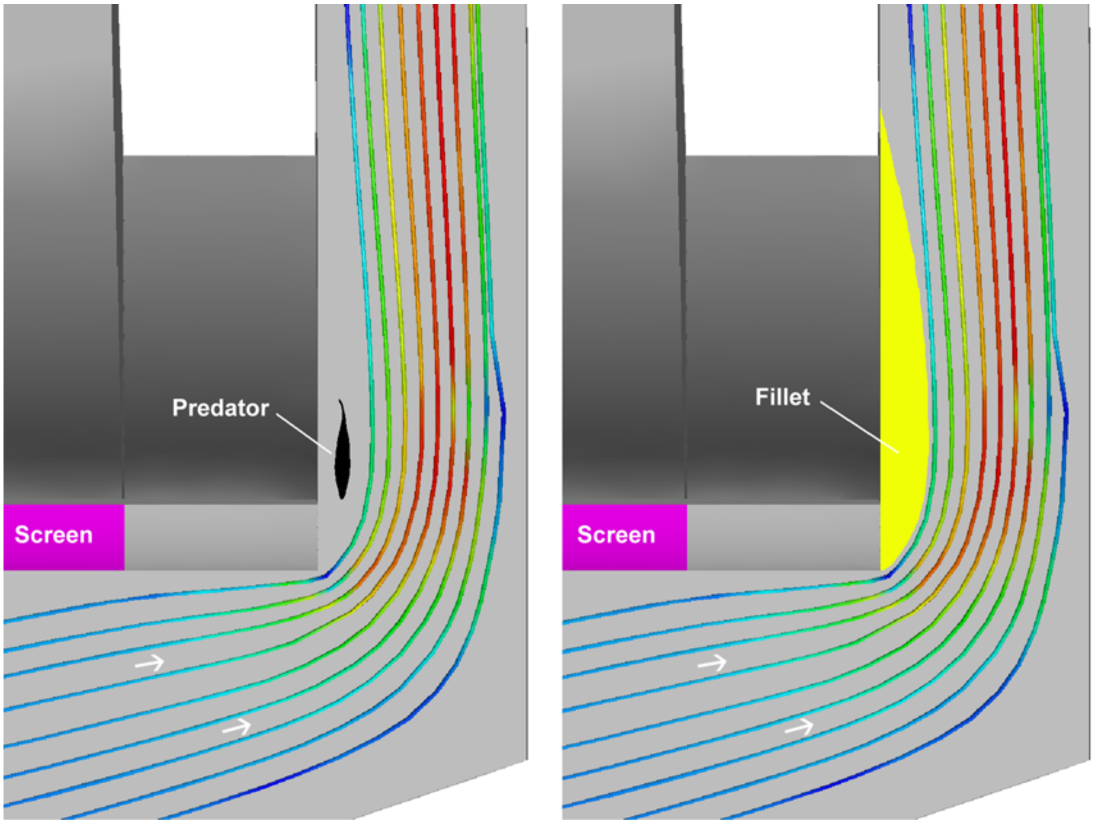

Figure 41. Plan view of a modeled entrance to the first intermediate bypass at the Chandler Canal Fish Screen Facility showing flow vectors. The left panel illustrates the low velocity location where predatory smallmouth bass were observed by McMichael and Johnson (2001). The panel on the right shows a conceptual concrete fillet (in yellow) to eliminate the low velocity holding area for predatory fish.

Juvenile salmonids migrating in open river systems often migrate near the center of the channel and near the surface. This is in contrast to what we have observed (by underwater video) at most screen facilities. At other screen facilities, we typically see juvenile salmonids in the lower portion of the water column, often very near the bottom.

As mentioned previously, a more quantitative model could be developed by using the existing model and collecting more validation data at the site. It would also have to be determined how the placement of these holes might affect the amount of water passing through the bypasses and into the separation chamber. It is possible that one effect of the holes would be a reduction of the amount of water passing into the bypasses. If desirable, adjustments to ramps and weirs, and/or cross-sectional area, may be able to compensate for flow changes within the bypasses. Further, the development of a more rigorous model would allow for identifying other configuration changes that could be implemented when/if the canal were to be operated under low flow conditions for prolonged periods in the future. For example, if canal flows were reduced (short-term [e.g., one season] or long-term [multiple years]), the placement of a guide wall that would effectively block off the upper bay of eight screens would be expected to increase forebay and sweep velocities at the facility. In addition, if canal flows were to be reduced long term (e.g., in the event of KID water exchange), then modifications to the canal that would increase velocity for the entire distance between the headworks and the bypasses would be expected to increase salmonid survival within the canal.

The bypass pipe from the JEF to the river should be vented to reduce surging. Also, all bypass pipes should continue to be inspected regularly for obstructions that may impinge fish or create hydraulic situations that might injure fish.

To address the predation issue within the facility, modifications to the bypass entrances (elimination of low velocity areas by concrete fillets combined with the placement of electrodes for shocking predators) are worthy of further investigation. A monitoring component should be implemented to evaluate the effectiveness of these potential modifications. It should also be noted that increasing the velocity through the entire canal would reduce the habitat availability (e.g., holding and foraging locations) for predatory fish such as smallmouth bass. Further, increased velocity (in a more confined channel) would be expected to reduce the effectiveness of avian predators such as herons, terns, kingfishers, mergansers, and gulls.

To determine the effect of passing through the canal and the JEF, a juvenile salmonid survival study should be conducted to compare the survival of fish that enter Chandler Canal to those that do not enter Chandler Canal. By comparing the survival of groups (canal passage versus no canal passage) of salmonids that emigrated through the lower Yakima River during similar time blocks, would allow for the determination of possible delayed mortality associated with passing through the canal. In addition, to better assess the effects of canal flow, date, and water temperature on canal survival, an experimental design could be implemented that would allow for the isolation of the effects of at least canal flow and date. Water velocity data could also be measured in this study to elucidate the effects of water velocity on canal survival of salmonids.

The traveling belt screens in the separation chamber should be replaced. The placement of four screens where there are now two should effectively place the mean approach velocities in the area within the NMFS criteria.

At canal flows less than 700 cfs, it may be advisable to operate the facility with up to half of the screens turned off (not rotating) and with the bypass water running under the weir gates in the downwell upstream of the separation chamber. Velocity data from the 600 and 692 cfs canal flows suggested that the reduced percent open area from the algae and diatom growth on the screens that were not rotating was an effective way to reduce approach velocity and increase sweep velocity. The CFD model could be used to further examine the expected effects of such changes in operations during a range of flow conditions.